ملخص مادة..

القياسات والنواقل الميكانيكية

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MEASUREMENTS

-INSTRUMENTS-

TEXT BOOK: EXPERIMENTAL METHODS FOR ENGINEERS – Eighth Edition-

1. يحتوي هذا الملخص على شرح مفصل للمادة بالاضافة الى بعض الامثلة والبروبلم من الكتاب ويحتوي على أسئلة سنوات محلولة .
2. تضم هذه المادة 8 شباتر .
3. مادة المد غالباً ما تكون اول 4 شباتر وتكون نمط الاسئلة (غالباً) على النحو التالي :

(Uncertainty / Least square method / Bridge circuit / تعريفات ودوائر و صح وخطأ)

4. مادة الفاينل تكون من شابتر (5 – 8) بالاضافة الى مادة المد :

{..... /U-tube manometer / Thermo couples / Diaphragm / optical methods)

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نستقبل ملاحظاتكم وإقتراحاتكم

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CH1

→ Sensitivity to Disturbance.

1. Zero drift / Bias describes

The effect where the zero reading of an instrument is modified by a change in ambient conditions.

2. Sensitivity drift / Scale factor drift.

The amount by which an instrument sensitivity of measurment varies as ambient condition change.

* (angular degree / bar) / °C ← units.

→ Sensitivity of Measurment

$$\frac{\text{Scale deflection}}{\text{Value of measurand producing deflection}}$$

Example

The following resistance values of a platinum resistance thermometer were measured at a range of temperatures. Determine the measurement sensitivity of the instrument in ohms/°

Resistance (Ω)	Temperature (°C)
307	200
314	230
321	260
328	290

Solution

If these values are plotted on a graph, the straight-line relationship between resistance change and temperature change is obvious.

For a change in temperature of 30°C, the change in resistance is 7 Ω. Hence the measurement sensitivity = 7/30 = 0.233 Ω/°C.

Example

A spring balance is calibrated in an environment at a temperature of 20°C and has the following deflection/load characteristic:

Load (kg)	0	1	2	3
Deflection (mm)	0	20	40	60

It is then used in an environment at a temperature of 30°C, and the following deflection/load characteristic is measured:

Load (kg)	0	1	2	3
Deflection (mm)	5	27	49	71

Determine the zero drift and sensitivity drift per °C change in ambient temperature.

Solution

① At 20°C, deflection/load characteristic is a straight line. Sensitivity = 20 mm/kg.
At 30°C, deflection/load characteristic is still a straight line. Sensitivity = 22 mm/kg

→ Zero drift (bias) = 5 mm (the no-load deflection)

② Sensitivity drift = 2 mm/kg → 30°c - 20°c

→ Zero drift/°C = 5/10 = 0.5 mm/°C

③ Sensitivity drift/°C = 2/10 = 0.2 (mm/kg)/°C

$\frac{22\,mm}{kg} - \frac{20\,mm}{kg} = \frac{2\,mm}{kg}$

CH 2

Basic Concepts

→ units for Mesurment (Instrument).

[1] Britsh units.

Length

12 in = ft , in = 2.54 cm , Yard = 3 ft

mile = 5280 ft ,

Weigth

Lb = 454 g
بونز

Time → second.

[2] SI units

Stantred International

length (m) , mass (kg) , Time (second)

* The advantages SI units :-

[1] Based on decimal measurment.

[2] More the 90 % of the system in the World is in SI units.

3 Derived unite.

These unite are taken from the original unite.

$$N = kg\frac{m}{s^2}$$

unite
- Dimentional
- non diamentional (unite = 1) diamention less.

→ what is use non diamention less units.

It is know from everybody in World.

2.7 Basic Concepts in Dynamic Mesurment

→ For any system it maybe desuribed interms Varible $X(t)$ in the from of D.E as follow :-

$$\underbrace{a_n \frac{d^n X_t}{dt^n}}_{\text{n-term}} + \underbrace{a_{n-1} \frac{d^{n-1} X_t}{dt^{n-1}}}_{\text{n-1 term}} + \cdots + a_2 \frac{d^2 X_t}{dt^2} + \underbrace{a \frac{dX}{dt}}_{\text{first order}} + \underbrace{a_0 X}_{\text{zero order}} = f(t)$$

second order

→ If $F(t) = 0$ then the system is free system.

↳ forcing function / exitation function.

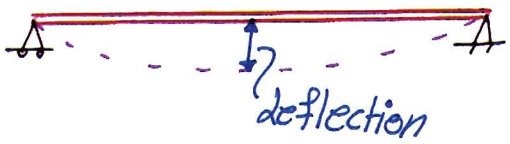
① Zero order system.

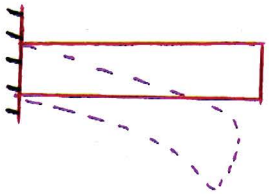
$$a_0 (X_t) = F(t)$$

$$X_t = \frac{1}{a_0} F(t)$$

↳ static sensitivity of the system.

→ If such describle a beam under deflection, so the static deflection of the beam is $\left(\frac{F(t)}{a_0}\right)$.



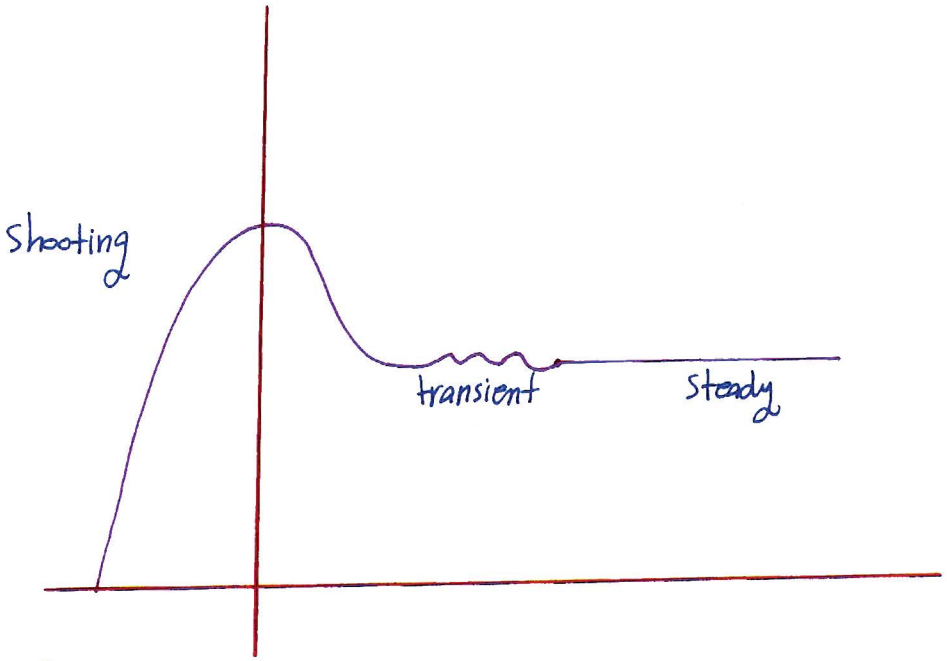


② First order System.

$$a\frac{dX_t}{dt} + a_0 X_t = F(t) \quad \div a_0$$

$$\frac{a}{a_0}\frac{dX_t}{dt} + X_t = \frac{1}{a_0}F(t)$$

Where $\frac{a}{a_0}$ is the time Constant (τ).



→ For the case of sudden Constant input $F(t) = A$ which is step Function, with the Conditions.

↳ Initial Condition.
↳ Boundary Condition.

$$\left.\begin{aligned} F(t) &= 0 \;,\; t = 0 \\ F(t) &= A \;,\; t > 0 \end{aligned}\right\}$$ Initial Condition.

→ Why we have shooting ?

Because we need to overcome the inertia of the mechanical system or the resistance (electrical system).

→ The Solution of the 1st order system.

$$X(t) = \underbrace{\frac{A}{a_0}}_{\text{Steady state function}} + \underbrace{\left(X_0 - \frac{A}{a_0}\right) e^{-t/\tau}}_{\text{transient}}$$

→ We will use the following Solution 1st order System.

$$\frac{X(t) - X_\infty}{X_0 - X_\infty} = e^{-t/\tau}$$

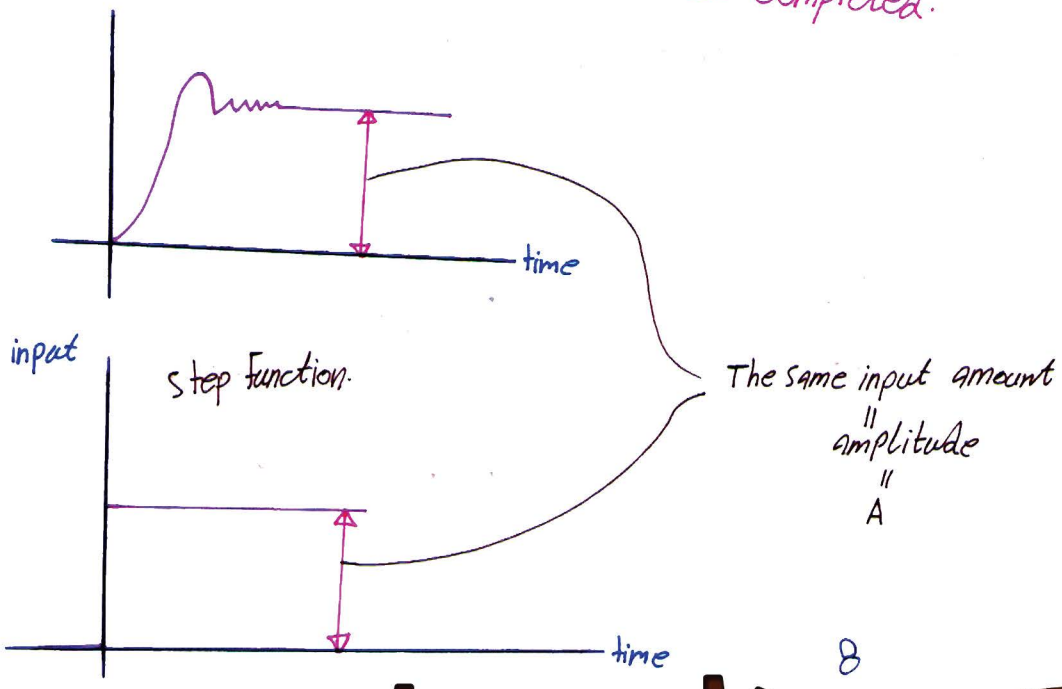
where :-

$X(t)$ = Value of X at any time (t).

X_∞ = final Value of X.

X_0 = Initial Value of X.

The percentage of the step input function to be Completed.



1 Time Constant (τ)

The needed time to reach a value of the input step function of 63.3 %

$$\frac{x_t - x_\infty}{x_0 - x_\infty} = e^{-t/\tau}$$

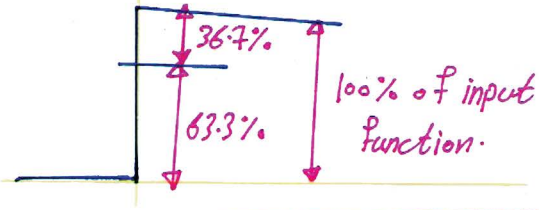
$100\% - 63.3 = 36.7\%$

$e^{-t/\tau} = 36.7\%$ Completly

$$\boxed{t = \tau}$$

$e^{-\tau/\tau} = \frac{1}{e} = 36.7\%$ The system has achieved τ

$100\% - 63.3\% = 36.7\%$



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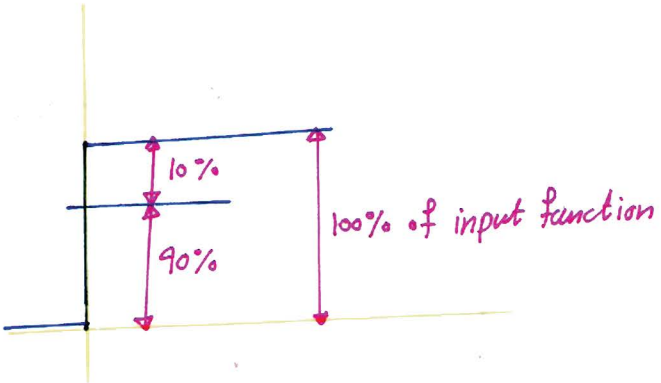
2 Rise time

Time need to achieve 90% of the step input function.

$$\frac{x_t - x_\infty}{x_0 - x_\infty} = e^{-t/\tau}$$

$e^{-t/\tau} = 0.1 \rightarrow \boxed{t = 2.3\tau}$

Completly 90%



[3] For 99.3 % of the input achived.

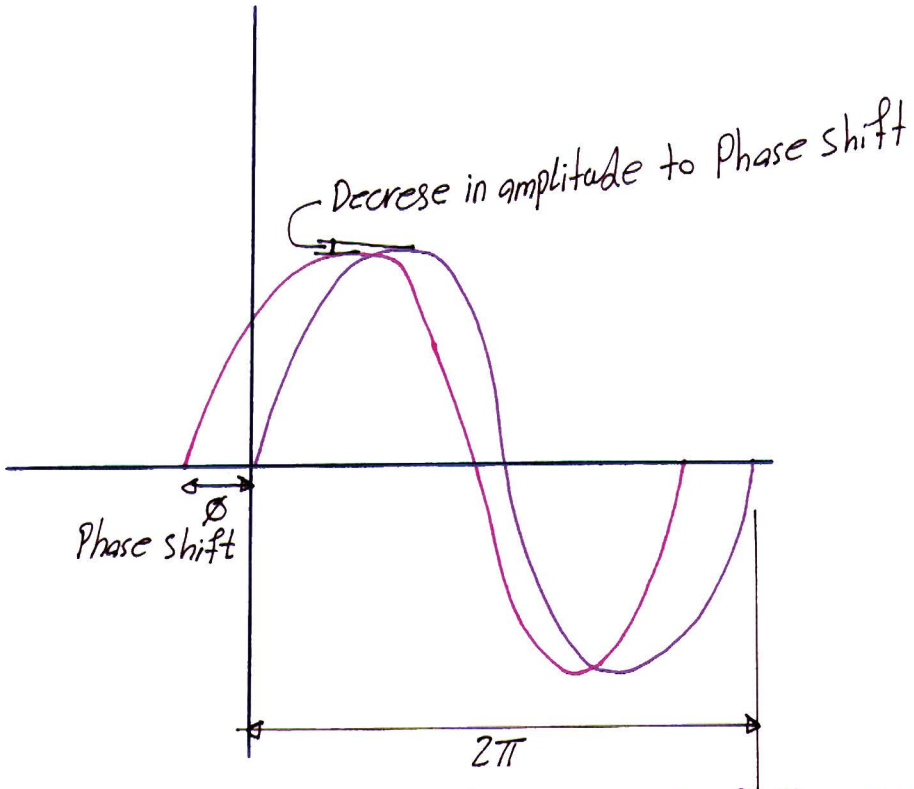
$e^{-t/\tau} = 0.7\%$ $\quad 100\% - 99.3\% = 0.7\%$

$\boxed{t = 5\tau}$

→ If the 1st order system is subjected to harmonic effect with inital Condition as $X = X_0$ at $t=0$ an $F(t) = A\sin\omega t$ to $t>0$ so the Solution will be $X(t) = Ce^{-t/\tau} + \frac{A/a_0}{\sqrt{1+(\omega t)^2}} \sin(\omega t - \tan^{-1}\omega t)$.

→ Harmonic function

Any function dependent a SinaSoidal input so the amplitude will be the Same after one Complete Cycle (2π) = the function repeats it self after 2π.



ω = frequency of the System for steady state part of the Solution.

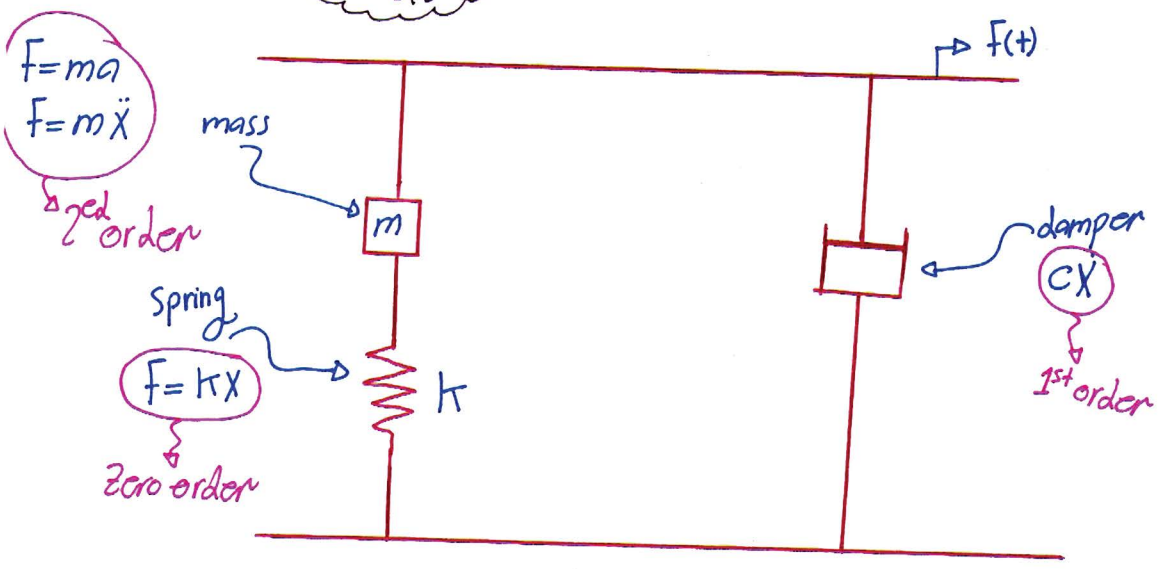
b) second order system.

$$a_2\frac{d^2x}{dt^2} + a\frac{dx}{dt} + a_0 x = f(t) = F_0 \cos\omega t \rightarrow \text{time}.$$

(F_0: Exiting force, ω: frequency)

→ The Can be represented by mass - Spring - Damper System.

$\dot{} = \frac{d}{dt}$



$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kc = F_0 \cos\omega t$$

The Solution is :-

$$X(t) = \frac{(F_0/k)\cos(\omega t - \phi)}{\sqrt{\left[1-(\omega/\omega_n)^2\right]^2 + \left[2(\frac{c}{c_c})(\frac{\omega}{\omega_n})\right]^2}}$$

$$\phi = \tan^{-1}\frac{2(c/c_c)(\omega_1/\omega_n)}{1-(\omega_1/\omega_n)^2} \quad , \quad \omega_n = \sqrt{\frac{k}{m}} \quad , \quad C_c = 2\sqrt{mk}$$

(ϕ: Phase angle (rad), ω_n: natural frequency, C_c: Critical damping Coefficient)

→ Natural frequency ω_n = The frequency of any system whitout any external force applied.

$$m\frac{d^2x}{dt^2} + C\frac{dx}{dt} + Kx = 0$$

it the depends on the mechincal properties of material.

$$[E, \rho, K, \eta]$$

C/C_c = damping ratio ζ (Zeta).

we have three case of damping :-

① $\zeta > 1$ over damping.

② $\zeta = 1$ Critically " .

③ $\zeta < 1$ under " .

$$\frac{\text{out Put amplitude}}{\text{in Put amplitude}} = \frac{X_o}{F_o/K} \quad \text{amplitude ratio}$$

$$X_o = \frac{F_o/K}{\sqrt{\left[1-\left(\frac{\omega_1}{\omega_n}\right)^2\right]^2 + \left[2\left(\frac{\zeta}{C_c}\right)\left(\omega_1/\omega_n\right)^2\right]}}$$

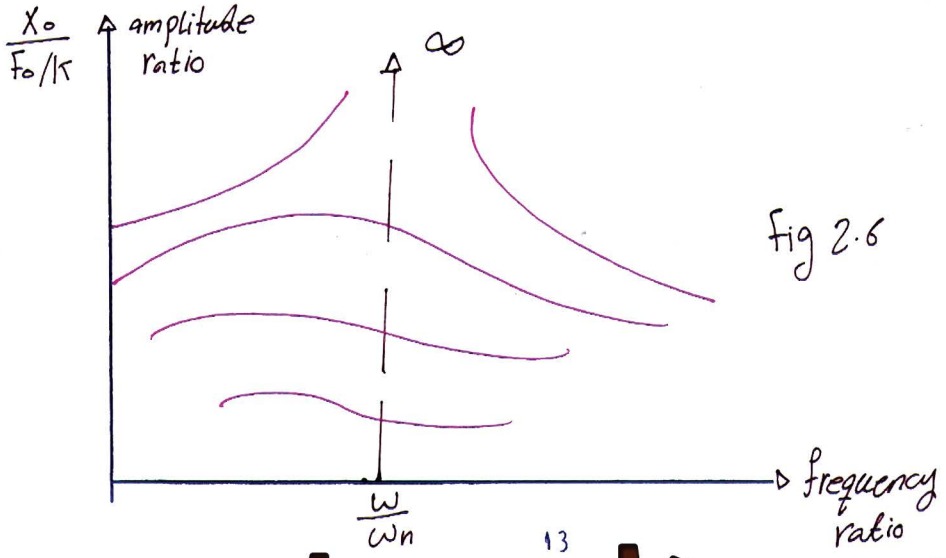


fig 2.6

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→ when $\omega = \omega_n$ or $\frac{\omega}{\omega_n} = 1$ the System under gose resonance. رنين

→ Why we need avoid resenance ?

The system will be destroyed to tall if the resonance has be reached.

سوف يُدمر النظام إذا أقتربنا من حالة الرنين.

CH3

Analysis of Experimental Data

3.4 uncertainty Analysis

→ Some times the uncertainty referes to the wrong results.

Partial Differentiation

1. $M = x^2 y$

$$\frac{\partial M}{\partial x} = 2xy \quad , \quad \frac{\partial M}{\partial y} = x^2$$

2. $M = \frac{x^2 y}{z}$

$$\frac{\partial M}{\partial z} = \frac{-x^2 y}{z^2}$$

For any function having the Varible as :-

$$R = R(x_1, x_2, \dots, x_n)$$

The uncertainty for $x_1 \rightarrow \omega_{x_1}$

$x_2 \rightarrow \omega_{x_2}$

$x_3 \rightarrow \omega_{x_3}$

$x_n \rightarrow \omega_{x_n}$

$$\omega_R = \sqrt{\left(\left(\frac{\partial R}{\partial x_1}\right)\omega_{x_1}\right)^2 + \left(\frac{\partial R}{\partial x_2}\omega_{x_2}\right)^2 + \dots + \left(\frac{\partial R}{\partial x_n}\omega_{x_n}\right)^2}$$

Solution Steps

① nominal value for the function, without any uncertainty.
② Perform the Partial diff for each variable.
③ Find ω_R.
④ Find the uncertainty Percentage $= \frac{\omega_R}{\text{nominal value}} \cdot 100\,\%$.

EX 3.1

$$R = R_o\left[1 + \alpha(T - 20)\right]$$

↳ resistance.

Variable +
$R_o = 6 \pm 0.3\,\%$
$\alpha = 0.004 \pm 1\,\%$
$T = 30 \pm 1$

← uncertainty

← نفك uncertainty الذي يوجد له Variable ال
Partial ل

ليست (%) لذلك تأخذ كما هي

Solution :-

① nominal value

$R = 6[1 + 0.004(30 - 20)] = 6.24\,\Omega$

② Partial Varible.

$\frac{\partial R}{\partial R_o} = [1 + \alpha(T - 20)] = 1.04$

$\frac{\partial R}{\partial \alpha} = R_o(T - 20) = 60$

$\frac{\partial R}{\partial T} = R_o\alpha = 0.024$

$\omega_{R_o} = 6 * \frac{0.3}{100} = 0.018$

$\omega_\alpha = 0.004 * \frac{1}{100} = 4 * 10^{-5}$

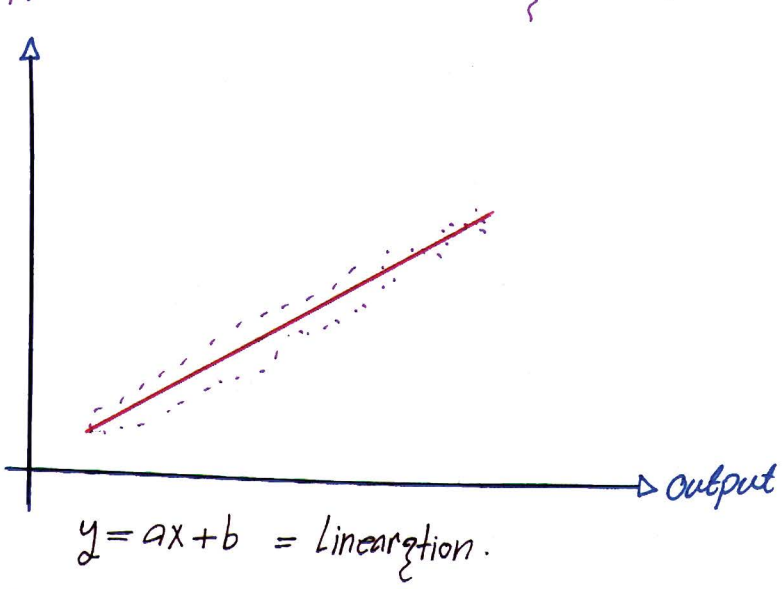
$\omega_T = 1$

[3] $\omega_R = \sqrt{(1.04 * 0.018)^2 + (60 * 4 * 10^{-5})^2 + (1 * 0.024)^2} = 0.0305\ \Omega$

[4] $\%\ \omega_R = \frac{0.0305}{6.24} * 100\ \% = 0.488\ \%.$

3.11 Least Square Method.

[1] This is an approximate method for Linearqtion of the output Data.



$y = ax + b$ = Linearqtion.

[2] The reason for using least square method is that the Linear Solution devides the output Point almost the same.

[1] Ordinary Linear Function.

$$\boxed{y = ax + b}$$

$$a = \frac{n \sum x_i y_i - \sum x_i \sum y_i}{n \sum x_i^2 - (\sum x_i)^2}$$

$$b = \frac{\sum y_i \sum x_i^2 - \sum x_i y_i \sum x_i}{n \sum x_i^2 - (\sum x_i)^2}$$

EX 3.19

x_i	y_i	$x_i y_i$	x_i^2
1	1.2	1.2	1
1.6	2	3.2	2.56
3.4	2.4	8.16	11.56
4	3.5	14	16
5.2	3.5	18.2	27.04
15.2	12.6	44.76	58.16

$$a = \frac{(5)(44.76) - (15.2)(12.6)}{(5)(58.16) - (231.04)} = 0.54$$

$$b = \frac{(12.6)(58.16) - (44.76)(15.2)}{(5)(58.16) - (231.04)} = 0.8779$$

$n = 5$

$(\Sigma x_i)^2 = (15.2)^2 = 231.04$

$$y = 0.54x + 0.8779$$

[2] Exponential Function Fitting

Find the beast fit for the following :-

$$y = A \cdot e^{bx} \quad , \quad A = e^{a}$$

$$a = \frac{\sum \ln y_i \sum x_i^2 - \sum x_i \ln y_i \sum x_i}{n \sum x_i^2 - (\sum x_i)^2}$$

$$b = \frac{n \sum x_i \ln y_i - \sum x_i \sum \ln y_i}{n \sum x_i^2 - (\sum x_i)^2}$$

[3] Power Function Fitting

$$y = Ax^{b} \quad , \quad A = 10^{a}$$

$$a = \frac{\sum \log y_i \sum \log x_i^2 - \sum \log x_i \log y_i \sum \log x_i}{n \sum (\log x_i)^2 - (\sum \log x_i)^2}$$

$$b = \frac{n \sum \log x_i \log y_i - \sum \log x_i \sum \log y_i}{n \sum (\log x_i)^2 - (\sum \log x_i)^2}$$

P3.29 Exponential Function

x_i	y_i	$\ln y_i$	x_i^2	$x_i \ln y_i$
0	9.4	2.2407	0	0
0.43	7.1	1.96	0.1849	0.8428
1.25	5.35	1.677	1.5625	2.096
1.4	4.2	1.435	1.96	2.009
2.6	2.6	0.955	6.76	2.484
2.9	1.95	0.667	8.41	1.9366
4.3	1.15	0.1397	18.49	0.6009
12.88		9.075	37.367	9.9699

مجموع

$y = A \cdot e^{bx}$, $A = 9.12315$

$A = e^a$ $a = 2.2108$

$b = -0.49235$

$\therefore y = 9.12315 \cdot e^{-0.49235x}$

[C] 3.27. The following data are expected to follow a linear relation of the form y $ax+b$. Obtain the best linear relation in accordance with a least-squares anal sis. Calculate the standard deviation of the data from the predicted straight-li relation:

x	0.9	2.3	3.3	4.5	5.7	6.7
y	1.1	1.6	2.6	3.2	4.0	5.0

[C] 3.28. The following data points are expected to follow a functional variation $y = ax^b$. Obtain the values of a and b from a graphical analysis:

x	1.21	1.35	2.40	2.75	4.50	5.1	7.1	8.1
y	1.20	1.82	5.0	8.80	19.5	32.5	55.0	80.0

3.22 PROBLEMS

9. The following data points are expected to follow a functional variation of $y = ae^{bx}$. Obtain the values of a and b from a graphical analysis:

x	0	0.43	1.25	1.40	2.60	2.9	4.3
y	9.4	7.1	5.35	4.20	2.60	1.95	1.15

P3.27

Ordinary Linear Function

	x_i	y_i	$x_i y_i$	x_i^2	
1	0.9	1.1	0.99	0.81	
2	2.3	1.6	3.68	5.29	
3	3.3	2.6	8.58	10.89	
4	4.5	3.2	14.4	20.25	
5	5.7	4	22.8	32.49	
6	6.7	5	33.5	44.89	
7	23.4	17.5	83.95	114.62	المجموع

$n = 7$

$a = 0.672$, $b = 0.2955$

$\therefore y = 0.672 + 0.2955x$

P3.28

Power Function

	X_i	y_i	$\log X_i$	$\log y_i$	$\log X_i \log y_i$	$(\log X_i)^2$
1	1.21	1.2	0.0828	0.079	$6.54 * 10^{-3}$	$6.8558 * 10^{-3}$
2	1.35	1.82	0.13	0.26	0.0338	0.0169
3	2.4	5	0.38	0.7	0.266	0.1444
4	2.75	8.8	0.44	0.944	0.41536	0.1936
5	4.5	19.5	0.653	1.29	0.842	0.4264
6	5.1	32.5	0.7075	1.512	1.07	0.5
7	7.1	55	0.85	1.74	1.479	0.7225
8	8.1	80	0.908	1.9031	1.728	0.8244
			4.1513	8.4281	5.8517	2.835

$a = -0.07316$, $A = 10^a = 0.8449$

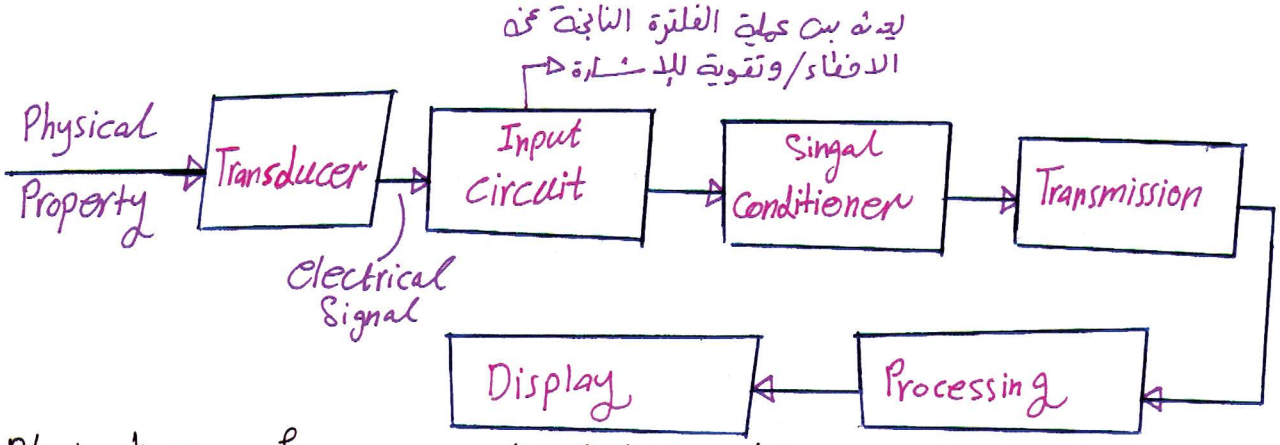
$b = 2.17$

$\therefore y = 0.8449 X^{2.17}$

CH4

Basic Electrical Measurments and Sensing Devices

4.6 Basic input Circuit



Block diagram of measurement and display / Physical property

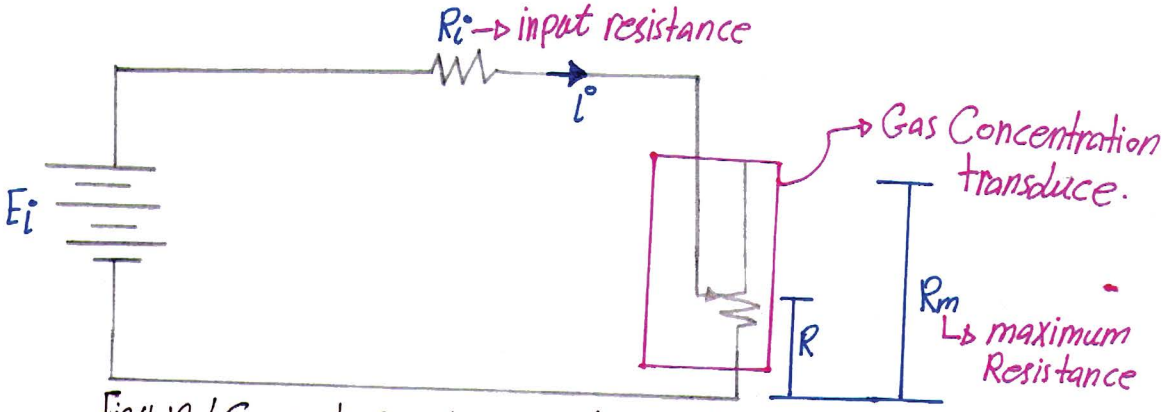
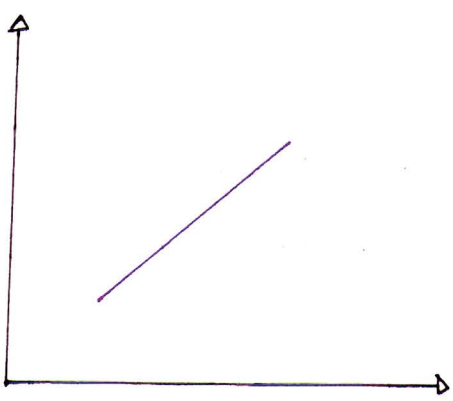


Fig 4.19 / Current-Sensitive input Circuit

[1] $i = \frac{E_i}{R + R_i}$ [2] $\frac{i}{E_i/R_i} = \frac{1}{(R/R_m)(R_m/R_i) + 1}$ (DimensionLess)



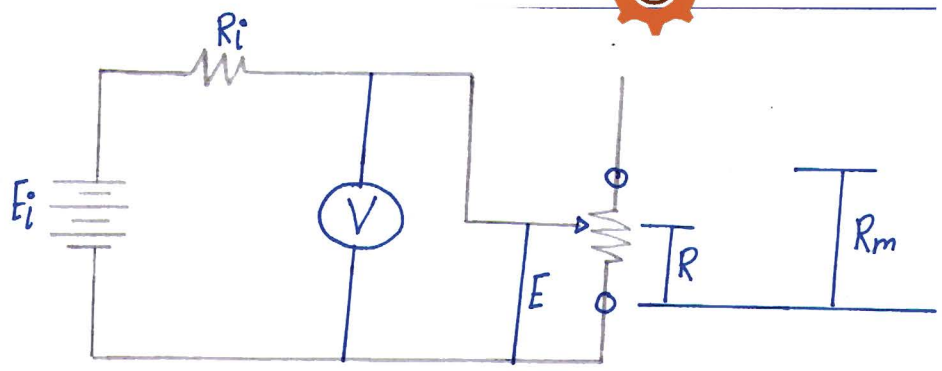


Fig 4.20 / Voltage Sensitive Circuit

[1] $i = \frac{E_i}{R + R_i}$ [2] $\frac{E}{E_i} = \frac{(R/R_m)\ (R_m/R_i)}{1 + (R/R_m)(R_m/R_i)}$

$\Rightarrow$ Sensitivty (S)

$$S = \frac{dS}{dR} = \frac{E_i\ R_i}{(R_i + R)^2}$$

$\Rightarrow$ Sensitivity Max (S_{max})

$$S_{max} = \frac{dS}{dR} = 0$$

*** for maximum sensitivity at the midpoint of the range.

$$R_i = \underbrace{R}_{\text{Variable}} = \frac{1}{2} R_m$$

*** If you are not in the midpoint (not max Sensitivity).

$$R_i \neq \frac{1}{2} R_m \ , \ R \neq R_i$$

*** - R_i only select Value at maximum sensitivity, $R_i = \frac{1}{2} R_m$.

- R is Varible, R = range at maximum Sensitivity.

- R/R_m = Percent position.

لجنة الميكانيك - الإتجاه الإسلامي

VOLTAGE SENSITIVITY. The output of a transducer with a total resistance of 150 Ω is to be measured with a voltage-sensitive circuit like that shown in Fig. 4.20. The sensitivity is to be a maximum at the midpoint of the transducer. Calculate the sensitivity at the 25 and 75 percent positions, assuming a voltage source E_i of 100 V. | **Example 4.1**

Solution

For maximum sensitivity at the midpoint of the range, we take

$$R_i = R = \tfrac{1}{2} R_m = 75\,\Omega$$

At the 25 percent position $R = (0.25)(150) = 37.5\,\Omega$, and the sensitivity is calculated from Eq. (4.15):

$$S = \frac{dE}{dR} = \frac{E_i R_i}{(R_i + R)^2} = \frac{(100)(75)}{(75 + 37.5)^2} = 0.592\ \text{V}/\Omega$$

At the 75 percent position the corresponding sensitivity is

$$S = \frac{(100)(75)}{(75 + 112.5)^2} = 0.213\ \text{V}/\Omega$$

LOADING ERROR OF VOLTAGE-SENSITIVE CIRCUIT. The voltage-divider circuit is used to measure the output of the transducer in Example 4.1. A 100-V source is used ($E_0 = 100$ V), and the internal resistance of the meter R_i is 10,000 Ω. Calculate the loading error at the 25 and 75 percent positions on the transducer and the actual voltage readings which will be observed at these points. | **Example 4.2**

Solution

We have

$$\frac{R_m}{R_i} = \frac{150}{10{,}000} = 1.5 \times 10^{-2}$$

At the 25 percent position $R/R_m = 0.25$ and the fractional loading error is calculated from Eq. (4.20*a*) as

$$\text{Fractional loading error} = -(0.25)(1 - 0.25) = 0.281\%$$

The deviation from linear is obtained from Eq. (4.20*b*)

$$\text{Deviation from linear} = \frac{-(0.25)^2(1 - 0.25)}{(0.25)(1 - 0.25) + 1/0.015} = -7.01 \times 10^{-4}$$

The indicated voltage is therefore

$$E = (100)(0.25 - 7.01 \times 10^{-4}) = 24.93\ \text{V}$$

At the 75 percent position $R/R_m = 0.75$ and

$$\text{Fractional loading error} = -(0.75)(1 - 0.75)(0.015) = 2.81 \times 10^{-3} = 0.281\%$$

The deviation from linear is

$$\text{Deviation from linear} = \frac{-(0.75)^2(1 - 0.75)}{(0.75)(1 - 0.75) + 1/0.015} = -2.103 \times 10^{-3}$$

and the indicated voltage is

$$E = (100)(0.75 - 2.103 \times 10^{-3}) = 74.79\ \text{V}$$

لجنة الميكانيك Polytechnic 25

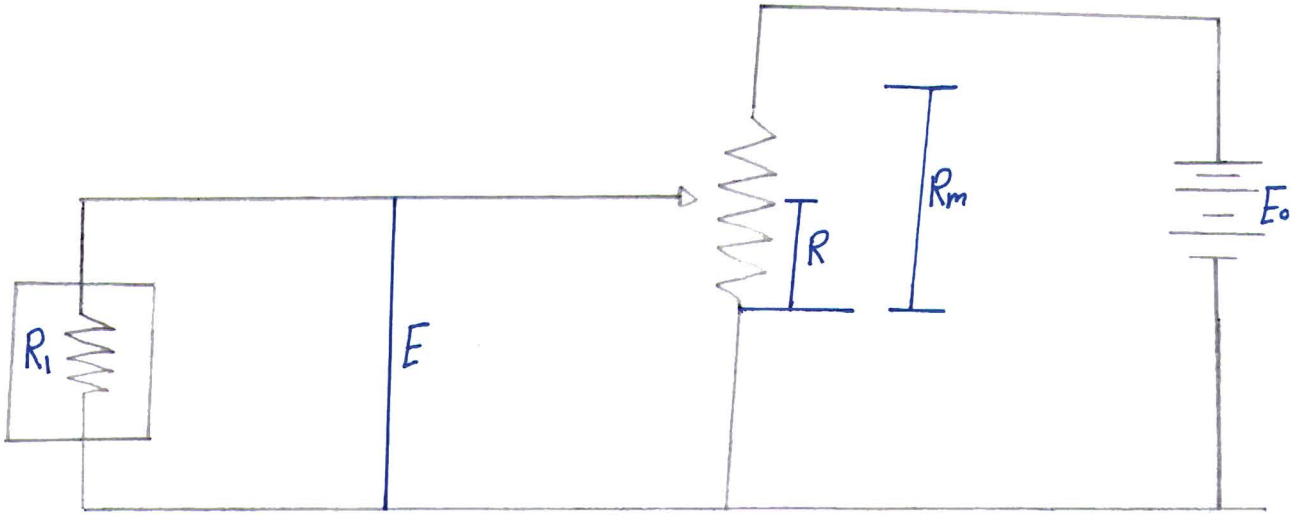


Fig 4.21 / Simple Voltage divider Circuit

[1] $\frac{E}{E_o} = \frac{R}{R_m}$, $R_i \gg R$

[2] $i = \frac{E_o}{R_m - R + R_i R/(R+R_i)}$, $E = E_o - i(R_m - R)$

E_o ← Supply Voltage

E ← Indicated Voltage

$$\frac{E}{E_o} = \frac{R/R_m}{(R/R_m)(1 - R/R_m)(R_m/R_i) + 1}$$

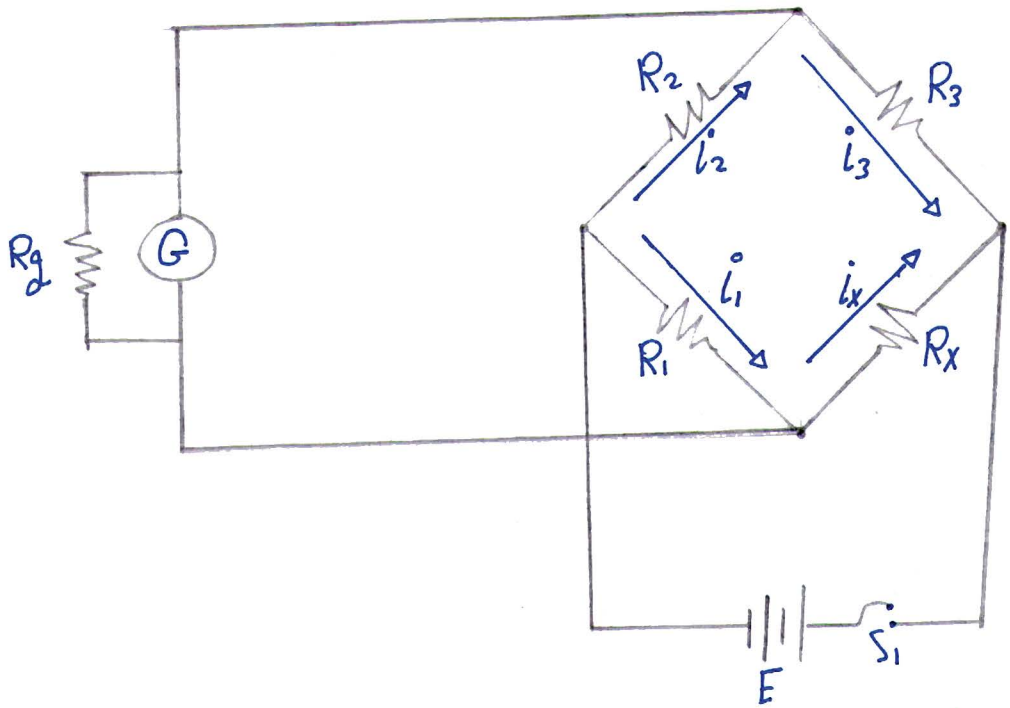
[3] Fractional Loading error $= -\left(\frac{R}{R_m}\right)\left(1 - \frac{R}{R_m}\right)\left(\frac{R_m}{R_i}\right)$

[4] Deviation from Linear $= \frac{-(R/R_m)^2 (1 - R/R_m)}{(R/R_m)(1 - R/R_m) + R_i/R_m}$

Bridge Circuit

1 Balanced Wheatsone Bridge. (Null Principle)

* No output Voltage.



→ The goal of this Circuit is find the unkwon resistance (Rx).

→ How it work : By switching this Circuit on, we keep changing the Variable resistance unitil the reading of the G is zero.

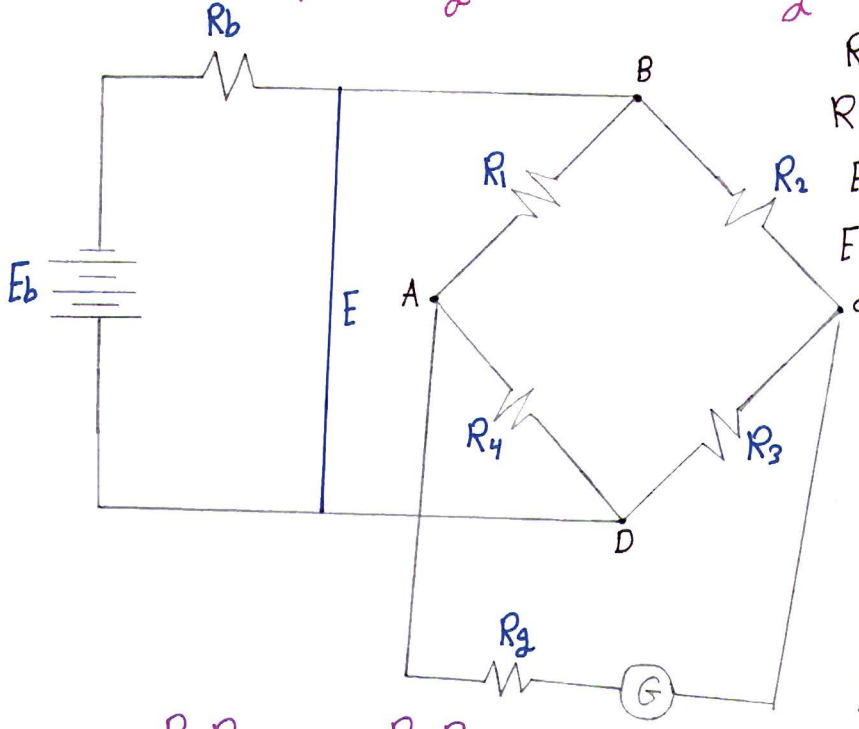
→ At the Balance of this circuit " G has zero reading".

$$i_2 = i_3 \;,\; i_1 = i_x$$

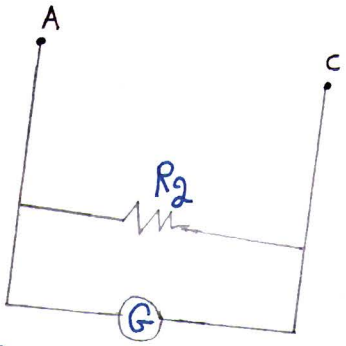
$$\frac{R_2}{R_3} = \frac{R_1}{R_x} \Rightarrow R_x = \frac{R_1 R_3}{R_2}$$

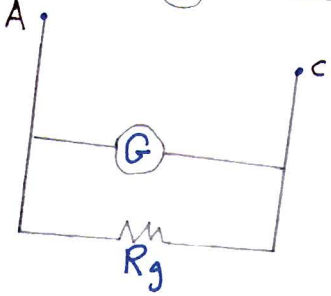
[2] Unbalance Bridge

* We have output voltage. * We have reading in the G



R_g = galvanometer resistance.
R_b = battery resistance.
E_g = Voltage glvanometer
E = Voltage bridge.



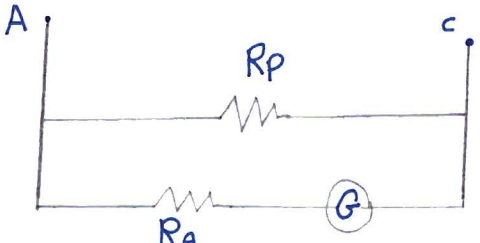


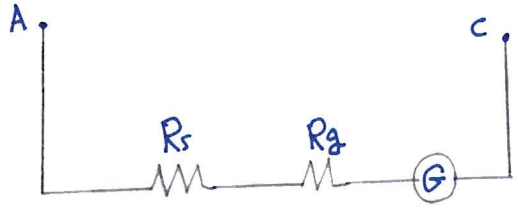
[1] $R = \frac{R_1 R_4}{R_1 + R_4} + \frac{R_2 R_3}{R_2 + R_3}$

[2] $E_g = F\left(\frac{R_1}{R_1 + R_4} - \frac{R_2}{R_2 + R_3}\right)$

[3] $R_o = \frac{(R_1 + R_4)(R_2 + R_3)}{R_1 + R_2 + R_3 + R_4}$ output resistance of the whole Circuit

[4] $E = E_b \frac{R_o}{R_o + R_b}$ [5] $i_g = \frac{E_g}{R + R_g}$





* $R_e = \frac{R_p R}{R_p + R}$ * $i_g = \frac{E_g}{R_e + R_g}$

* $i_g = \frac{E_g}{R + R_g + R_s}$

→ The used Circuit to the unbalanced Circuit bridge is Called Current Sensitive Circuit.

→ If the deflection measurment is made by instrument like electronic Voltmeter, Osciliscope on other high impedance device only $i_g \to 0$, $R_g \to \infty$.

6 $S = \frac{i_g}{\text{Deflection(mm)}}$

4.7 Amplifier

$$\text{Gain} = \frac{E_o}{E_i} = A$$

usually we add the feedback Loop which attenuates the output Voltage by a factor (K).

$E_f = K E_o$ → output voltage
- K → attenuates
- E_f → feedback voltage

→ Amplifier feedback

$$A_f = \frac{E_o}{E_i} = \frac{A}{1 + KA}$$

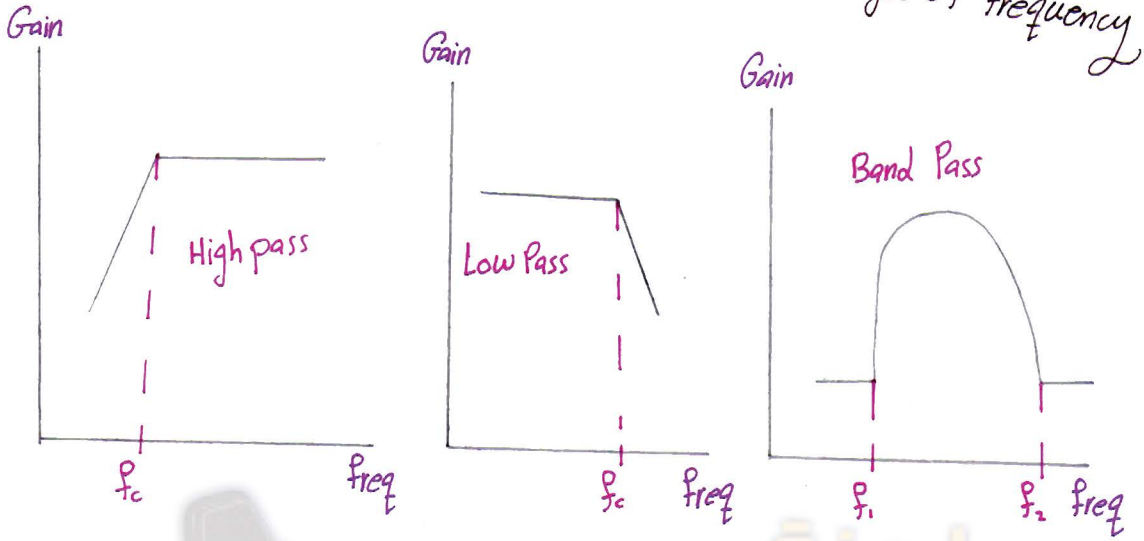
* If $KA \ggg 1 \to A_f = \frac{1}{K}$

* If $K = 0 \to A_f = A$

** $E_o = \frac{E_i}{K} \pm \frac{N}{KA}$

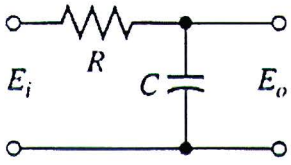
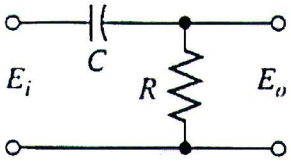
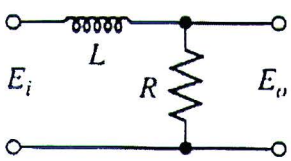
4.12 Singal Conditioning

The Important task to transmit or pass only Certain bands.
ranges of frequency



– Filters –

Table 4.2 Some simple *RL* and *RC* filter sections

Diagram	Type	Time Constant	Formula and Asymptotic Approximation
	A lowpass *RC*	$T = RC$	$\frac{E_o}{E_i} = \frac{1}{\sqrt{1+\omega^2T^2}} \approx \frac{1}{\omega T}$ $\phi_A = -\tan^{-1}(R\omega C)$
	B highpass *RC*	$T = RC$	$\frac{E_o}{E_i} = \frac{1}{\sqrt{1+\frac{1}{\omega^2T^2}}} \approx \omega T$ $\phi_B = \tan^{-1}\frac{1}{R\omega C}$
	C lowpass *RL*	$T = \frac{L}{R}$	$\frac{E_o}{E_i} = \frac{1}{\sqrt{1+\omega^2T^2}} \approx \frac{1}{\omega T}$ $\phi_C = -\tan^{-1}\frac{\omega L}{R}$

$$m = \sqrt{1 - \left(\frac{f_c}{f_\infty}\right)^2}$$ - Low Pass -

$$m = \sqrt{1 - \left(\frac{f_\infty}{f_c}\right)^2}$$ - High Pass -

m = Derived Value.
f_∞ = optimum.
= final Value of freq.
= steady state Value.
f_c = Cutoff frequency.

→ For all case take $m = 0.6$

Degree of Attenuation

$$G = \frac{output}{input}$$

→ For Power → Decibles $= 10 \log \frac{P_2}{P_1}$
→ For Voltage → // $= 20 \log \frac{E_2}{E_1}$
→ For current → // $= 20 \log \frac{I_2}{I_1}$

For passive filters the ratio of output to input $(\frac{E_2}{E_1})$ is less than 1 (Decible is negative).

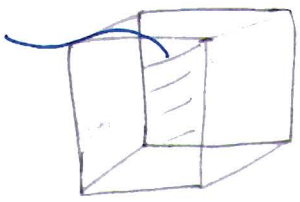
4.22 Capacitive Transducers

$$C = 0.225\, E \frac{A}{d_{in}}\ (in^2),\quad C = 0.0885\, E \frac{A}{d_{cm}}\ (cm^2)$$

C: Capacitance (F) فاراد

E = 1 air , 3 Plastic

المساحة المشتركة بين اللوحين (A)



$$Z = \frac{1}{2\pi f C}$$

Z: Impedance (Ω), f: Hz

ample 4.6 | **VOLTAGE AMPLIFICATION.** A 1.0-mV signal is applied to an amplifier such that an output of 1.0 V is produced. The 1.0-V signal is then applied to a second amplification stage to produce an output of 25 V. For the three voltage points indicated, calculate the voltage in decibel notation referenced to (*a*) 1.0 mV and (*b*) 1.0 V. Also, calculate the overall voltage amplification in decibels.

Solution

The schematic for the amplifiers is shown in Fig. Example 4.6.

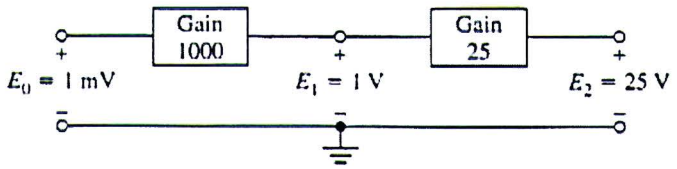


Figure Example 4.6

(*a*) For $E_0 = 1.0$ mV we have

$$20 \log \frac{E_1}{E} = \text{dB}_1$$

$$20 \log \frac{E_0}{E_0} = 20 \log \frac{1.0 \times 10^{-3}}{1.0 \times 10^{-3}} = \text{dB}_1 \qquad \text{dB}_1 = 0$$

$$20 \log \frac{E_1}{E_0} = 20 \log \frac{1.0}{1.0 \times 10^{-3}} = \text{dB}_2 \qquad \text{dB}_2 = 60$$

$$20 \log \frac{E_2}{E_0} = 20 \log \frac{25}{1.0 \times 10^{-3}} = \text{dB}_3 \qquad \text{dB}_3 = 87.92$$

(*b*) For $E_0 = 1.0$ V we have

$$20 \log \frac{E_0}{E_1} = 20 \log \frac{1.0 \times 10^{-3}}{1.0} = \text{dB}_1 \qquad \text{dB}_1 = -60$$

$$20 \log \frac{E_1}{E_1} = 20 \log \frac{1.0}{1.0} = \text{dB}_2 \qquad \text{dB}_2 = 0$$

$$20 \log \frac{E_2}{E_1} = 20 \log \frac{25}{1.0} = \text{dB}_3 \qquad \text{dB}_3 = 27.92$$

The overall amplification is calculated from

$$20 \log \frac{E_3}{E_1} = 20 \log \frac{25}{1.0 \times 10^{-3}} = 87.92 \text{ dB}$$

Notice that this result could have been obtained from the decibel calculations in (*a*) and (*b*) for either reference level. In other words

أسئلة سنوات (2017 -2019)

Q_1: tube of circular cross section has a nominal length of 52 ± 0.5 cm, an outside diameter of 20 ± 0.04 cm and an inside diameter of 15 cm ± 0.6% determihe the uncertainty In the calculated tube volume.

Sol $V_{tube} = \frac{\pi D_o^2}{4} L - \frac{\pi D_i^2}{4} L$

$\frac{\partial V}{\partial L} = \frac{\pi D_o^2}{4} - \frac{\pi D_i^2}{4} = 137.44$

$\frac{\partial V}{\partial D_o} = \frac{2\pi D_o L}{4} = 1633.63$

$\frac{\partial V}{D_i} = -\frac{2\pi D_i L}{4} = -1225.22$

$W_L = 0.5$

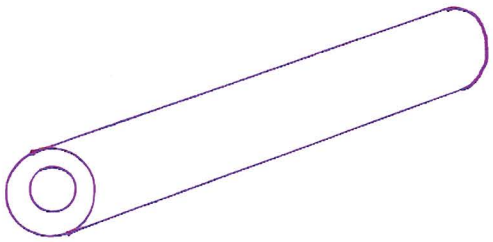
$W_{D_o} = 0.04$

$W_{D_i} = 15 * \frac{0.6}{100} = 0.09$

$W_V = \sqrt{(137.44 * 0.5)^2 + (1633.63 * 0.04)^2 + (1225.22 * 0.09)^2} = 145.43$

→ Volume nominal Value $= \frac{\pi D_o^2 L}{4} - \frac{\pi D_i^2 L}{4} = 7147$

→ $\% W_V = \frac{145.43}{7147} * 100\% = 2.034\%$



Q_2: a swimming pool has the following dimensions: width W= 7.5 ± 0.05 m, length L= 16 ± 0.05 m takes 7 and half hours to fill up the depth D which equals 1.5 m. If the uncertainty in the time is ±30 sec, determine the uncertainty in the flow rate in L/min.

Sol $\quad$ Flow rate $= \frac{\text{Volume}}{\text{time}} = \frac{L*W*D}{t}$

$\frac{\partial f}{\partial L} = \frac{WD}{t} = 0.025$, $\frac{\partial f}{\partial W} = \frac{LD}{t} = 0.053$, $\frac{\partial f}{\partial t} = \frac{-LWD}{t^2} = -8.88*10^{-4}$

($7.5*60 = 450$ min

$w_L = 0.05$, $w_W = 0.05$, $w_t = \frac{30}{60} = 0.5$

$w_f = \sqrt{(0.025*0.05)^2 + (0.053*0.05)^2 + (8.88*10^{-4}*0.5)^2} = 2.96*10^{-3}$ m^3/min

$\therefore 2.96*10^{-3}*1000 = 2.96$ L/min

Q_3: A vessel contains 2 kg of air at 25 C, if the ideal gas relation is PV = mRT ,if volume the V=1.3 m^3 ± 2%, pressure P =150 kPa ± 0.01 % and the gas constant R=287 J/kg.°K an experiment been performed to determine the uncertainty of the mass Which found to be 1.5% Determine the uncertainty in the temperature T.

Sol

$$m = \frac{PV}{RT}$$ كلفن

$$\frac{\partial m}{\partial V} = \frac{P}{RT} = 1.754 \;,\; \frac{\partial m}{\partial P} = \frac{V}{RT} = 1.52*10^{-5}$$

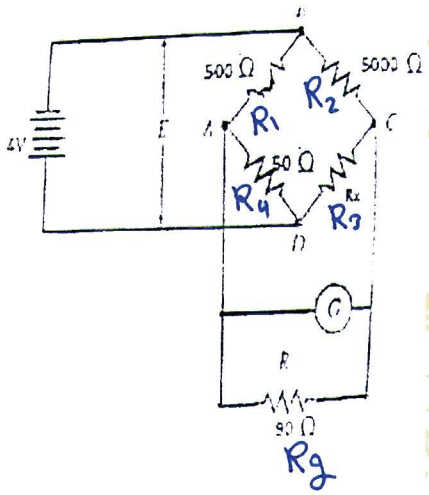
$$\omega_V = 1.3 * \frac{2}{100} = 0.026 \;,\; \omega_P = 150 * \frac{0.01}{100} = 0.015$$

$$\omega_m = \sqrt{(1.754*0.026)^2 + (1.52*10^{-5}*0.015)^2} = 0.0456$$

$$\text{nominal mass} = \frac{PV}{RT} = 2.3$$

$$\%\omega_m = \frac{0.0456}{2.3} * 100 = 2\ \%$$

Q_4: For the shown arrangement of wheatstone bridge with E=4V, if the galvanometer voltage is 0.7×10^{-3} V and its deflection is 1m Find the Unknown resistance Rx and the galvanometer sensitivity.



Sol $E_g = 0.7*10^{-3}V$, $D=1m$, $E=4V$

$$E_g = E\left(\frac{R_1}{R_1+R_4} - \frac{R_2}{R_2+R_3}\right)$$

$$0.7*10^{-3} = 4\left(\frac{500}{500+50} - \frac{5000}{5000+R_3}\right)$$

$$R_3 = R_x = 501.06\ \Omega$$

$$R = \frac{R_1R_4}{R_1+R_4} + \frac{R_2R_3}{R_2+R_3} = \frac{500*50}{500+50} + \frac{5000*501.06}{5000+501.06} = 500.9\ \Omega$$

$$i_g = \frac{E_g}{R+R_g} = \frac{0.7*10^{-3}}{500.9+90} = 1.1846*10^{-6}A$$

$$S = \frac{i_g}{D(mm)} = \frac{1.1846*10^{-6}A}{1m} = 1.1846*10^{-6}A/m$$

Q_5: According to a certain experiment following a first order system relation following data were taken ($y=ae^{bx}$).

x	1	2	3	4	5	6	7	10	15	20
y	0.09516	0.1813	0.2592	0.3297	0.3935	0.4512	0.5034	0.6321	0.7769	0.8647

Determine by the least square method the best values of y as a function of x.

	1	2	3	4	5	6	7	8	9	10
X^2	1	4	9	16	25	36	49	100	225	400
Lny	-2.352	-1.707	-1.35	-1.11	-0.93	-0.8	-0.686	-0.458	-0.252	-0.145
xlny	-2.352	-3.414	-4.05	-4.44	-4.65	-4.8	-4.802	-4.58	-3.78	-2.9

$$a = \frac{\Sigma \ln y \, \Sigma X - \Sigma X \ln y \, \Sigma X}{n \Sigma X_i^2 - (\Sigma X_i)^2} = \frac{9.79 * 73 - 39.574 * 73}{10 * 885 - (73)^2} = 0.654$$

$b = 0.096$

$$y = Ae^{bx}, \quad A = e^a = e^{0.654} = 1.923$$

$$\therefore y = 1.923\, e^{0.096x}$$

Q_6: A barometer is working according to the first order system has a time constant of 12 sec and has initially pressure value of 100 kPa. The barometer suddenly exposed to a pressure of 300 kPa, determine:

a) The rise time and the pressure at that time
b) What was the pressure when the time constant of the barometer has been achieved.

Sol

[1] rise time → 90%

$$e^{-t/\tau} = 0.1$$

$$t = 2.3\tau = 2.3 * 12 = 27.6 \text{ sec}$$

$$\frac{P(t) - P_\infty}{P_0 - P_\infty} = e^{-t/\tau}$$

$$\frac{P(t) - 300}{100 - 300} = 0.1 \rightarrow P(t) = 280 \text{ kPa}$$

[2] Time Constant → 63.3%

$$t = \tau = 12$$

$$\frac{P(t) - P_\infty}{P_0 - P_\infty} = e^{-t/\tau} = 0.367$$

$$\frac{P(t) - 300}{100 - 300} = 0.367$$

$$P(t) = 226.6 \text{ kPa}$$

Q_7: A vessel at 25 °C contains 2 kg of air, if the ideal gas relation is:

$$m = \frac{PV}{RT}$$

if P=150 kPa ± 0.01%
V =1.3 m^3 ± 2%
R=287 J/kg.°K

If the uncertainty in measuring or calculating the mass (m) is 1.5 %.

Find the uncertainty in temperature (T).

Q_8: A manometer is used to measure the static pressure of a turbulent flow, if the flow is fluctuating according to the following relation:

$$1.5\frac{d^2h}{dt^2} + 6\frac{dh}{dt} + 5h = 3\sin 4t$$

When t=3 sec. determine the type of the damping system, and the final output (h).

Sol

$$1.5\frac{d^2h}{dt^2} + 6\frac{dh}{dt} + 5h = 3\sin 4t$$

m c K F_o ω

$$\omega_n = \sqrt{\frac{K}{m}} = \sqrt{\frac{5}{1.5}} = 1.82.$$

$$C_c = 2\sqrt{Km} = 2\sqrt{5*1.5} = 5.477.$$

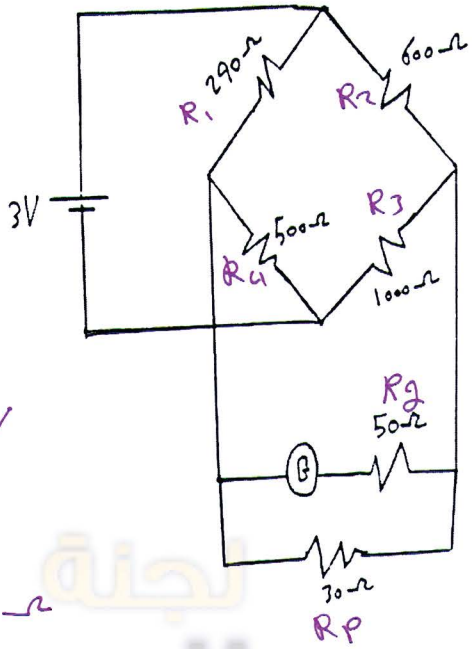
$$\phi = \tan^{-1}\frac{2(c/c_c)(\omega/\omega_n)}{1-(\omega/\omega_n)^2} = \tan^{-1}\frac{2(6/5.477)(4/1.82)}{1-(4/1.82)^2}$$

$$= -51.6°$$

$$h(t) = \frac{(F_o/K)\cos(\omega t - \phi)}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[(c/c_c)(\omega/\omega_n)2\right]^2}} = \frac{(3/5)\cos(4*3 - -51.6)}{\sqrt{\left[1-(4/1.82)^2\right]^2 + \left[2*(6/5.477)(\frac{4}{1.82})\right]^2}}$$

$$= 0.0433$$

Q_9: Find the deflection ; sensitivity of G =0.05 mA/mm



Sol $R = \frac{R_1 R_4}{R_1 + R_4} + \frac{R_2 R_3}{R_2 + R_3}$

$= \frac{290 * 500}{290 + 500} + \frac{600 * 1000}{600 + 1000} = 558.54\ \Omega$

$E_g = E\left(\frac{R_1}{R_1 + R_4} - \frac{R_2}{R_2 + R_3}\right)$

$= 3\left(\frac{290}{290 + 500} - \frac{600}{600 + 1000}\right) = 0.022\ V$

$R_e = \frac{R_p R}{R_p + R} = \frac{30 * 558.54}{30 + 558.54} = 28.47\ \Omega$

$I_g = \frac{E_g}{R_e + R_g} = \frac{0.022}{28.47 + 50} = 2.8 * 10^{-4}\ A$

$D = \frac{i_g}{S} = \frac{2.8 * 10^{-4}}{0.05 * 10^{-3}} = 5.6\ mm$

→ If $R = 30$ series with R_g

$i_g = \frac{E_g}{R + R_g + R_s} = \frac{0.022}{558.54 + 50 + 30} = 3.445 * 10^{-5}\ A$

$D = \frac{i_g}{S} = \frac{3.445 * 10^{-5}}{0.05 * 10^{-3}} = 0.689\ mm$

Q_{10}: Define the following:

a) Precision

b) Analogue instrument

c) Dead space

d) Zero drift

Q_9: State if the following are true (V) or false (X):

X	All measuring instruments must have variable conversion element to get correct results
X	The starting of measuring instruments was with the industrial revolution in Europe
✓	Resonance is happened when the frequency ratio equals a unity
✓	Passive instruments are very simple and directly used for measurement process
X	For vibration systems based on functions not necessarily to be a harmonic
✓	Much accurate results may obtained by using digital instruments compared to analogue ones
X	Deflection type instruments output based on discrete steps with finite value
X	Bias is another name for sensitivity drift
X	Precise instruments simply means devices with high accuracy
✓	Uncertainty sometimes stands for inaccuracy
X	For small damping ratios, the amplitude reduced strongly
X	Bridge circuits can only be used for the resistances and capacitance measurements

CH5

Displacement and Area Measurment

→ Dimensional Measurments (Lenght, width, area, Volume).

→ Displacement Measurments (movment from location to another).

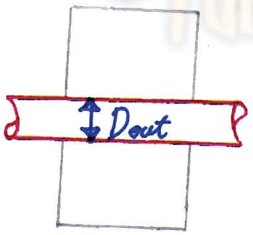
5.2 Dimensional Measurment.

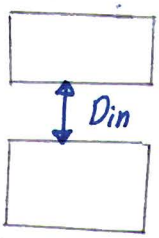
$$\text{Length} = L_o(1+\alpha\Delta T) = L_o(1+\alpha(T-T_o))$$

- α → Coefficent expansion.
- L_o → orignal Length (indication Length) (true distance)
- Length → distance Measurment
- T_o → true reading

5.3 Gage Blocks

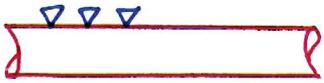
Tolerances: The range of Maximum and Minamum allowble dimention.





Dout of the shaft < Din of the Piece

one ▽ → Smooth
two ▽ → Very Smooth
three ▽ → extremilly Smooth



Filler gauge: used for the valves of the material Compesion angle.

Optical Methods

$\Delta(2d) = X \frac{\lambda}{2}$ ← Distance between the two surfaces

X: Fringes يعتمد على عدد

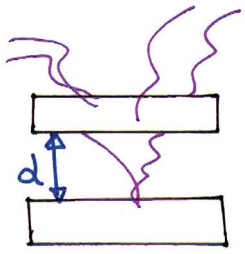
λ → Wave Light Length

$A^\circ = 10^{-10} m = 10^{-8} cm$ (انغستروم)

Fringes	X
1	1
2	3
3	5
4	7
5	9
6	11
7	13

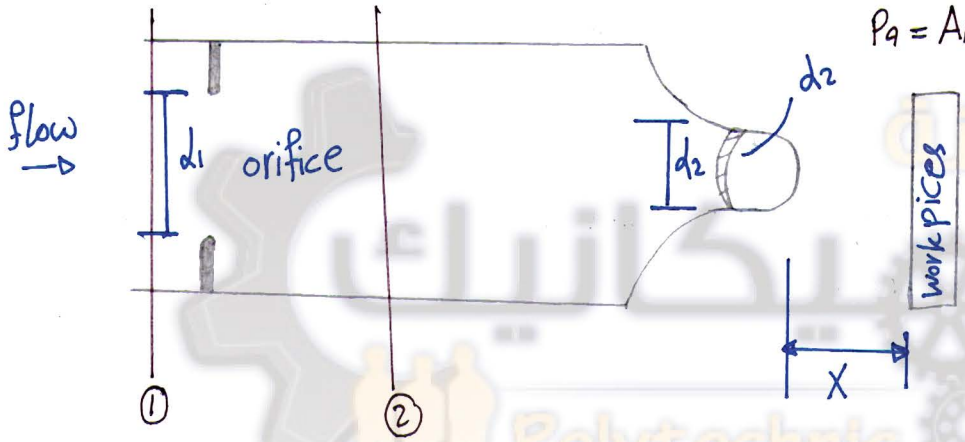
$\phi = \tan^{-1} \frac{d}{\text{total distance}}$ ← Given

ϕ: tilt angle



5.5 Pneumatic Displacement gauge.

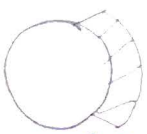
P_a = Ambient pressure.



$$Q = C_1 A_1 \sqrt{P_1 - P_2} = C_2 A_2 \sqrt{P_2 - P_a}$$

$$r = \frac{P_2 - P_a}{P_1 - P_a} = \frac{1}{1 + (A_2/A_1)^2}$$

$$A_1 = \frac{\pi d_1^2}{4} \quad , \quad A_2 = \pi d_2 X$$



$S = d\pi$

$A = d\pi X$

$$(r) = 1.1 - 0.5 \frac{A_2}{A_1} \qquad (0.4 < r < 0.9)$$

$$(r) = 1.1 - 2 \left(\frac{d_2^2}{d_1^2}\right) X$$

ple 5.1 **ERROR DUE TO THERMAL EXPANSION.** A 30-m (at 15°C) steel tape is used fo surveying work in the summer such that the tape temperature in the sun is 45°C. A measuremen indicates 24.567 ± 0.001 m. The linear thermal coefficient of expansion is 11.65 × 10^{-6}/°C at 15°C. Calculate the true distance measurement.

Solution

The indicated tape length would be the true value if the measurement were taken at 15°C. A the elevated temperature the tape has expanded and consequently reads too small a distance The actual length of the 30-m tape at 45°C is

$$L(1 + \alpha\,\Delta T) = [1 + (11.65 \times 10^{-6})(45 - 15)](30) = 30.010485 \text{ m}$$

Such a true length would be indicated as 30 m. The true reading for the above situation is thu

$$(24.567)[1 + (11.65 \times 10^{-6})(45 - 15)] = 24.576 \text{ m}$$

Example 5.4 Area of zero circle for planimeter. A planimeter with a fixed tracing arm 4.00 in long has a wheel circumference of 2.50 in. The instruction sheet for the instrument is lost so that the area of the zero circle is not known. To determine the area of th zero circle a certain area is measured with the pole both inside and outside the area. With the pole outside the area, the wheel records 2.5 revolutions (r). With the pole inside the area, the wheel records −13.01 r Calculate the area of the zero circle and the reading of the planimeter when it i used to trace out a circle with a 9-in radius.

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5.7 Planimeter (For area measurment).

EX:- tracing arm = 4in.

Wheel circumference = 2.5 in.

Pole out side area = 2.25 revolutions (r).

Pole in side area of the sheel = -13.1 (r).

Circle radius = 9 in.

Sol

A = tracing arm X out side area X Circumference.

$4 \times 2.25 \times 2.5 = 25.5\ in^2$

A_o = A - tracing arm X in side area X Circumference.

$= 25.5 - 4 \times (-13.1) \times 2.5 = 155.6\ in^2$

$$S = \frac{A - A_o}{L} = \frac{\pi (9)^2 - 155.6}{4} = 24.717$$

$$\underset{\text{wheel rev}}{n} = \frac{S}{2.5} = \frac{24.717}{2.5} = 9.887$$

2.5 ← wheel circumference.

CH6

Pressure Measurment

6.1 Introduction.

Pressure

- **Atmosphere Pressure**
  - ① $P_a = 101.325\ kPa$
  - ② Sea Level Pressure
- **Absolute Pressure**
  - $P_{abs} = P_{atm} + P_g$
- **Pressure gage**
  - ① Any Pressure measurment
  - ② appears the gage
- **Vacume Pressure**
  - Any Pressure under atm Pressure.

→ Normally $P_{atm} = 0$ why ?

① it is same from all direction, it cancels each other.
② it is same from any level.
③ it is always calculated about the gage Pressure.

* $P_{atm} = 101.325\ kPa = 14.7\ Psi = 760\ mmHg$
* $ft = 12\ in$ * $ft^2 = 144\ in^2$ * $Psi = \frac{lb}{in^2}$
* $1\ torr = 1\ mm\,Hg = 133.3\ Pa.$

6.2 Dynamic Response Consideration.

① $\left|\frac{P}{P_o}\right| = \frac{1}{\sqrt{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)^2 + 4h^2\left(\frac{\omega}{\omega_n}\right)^2}}$ (Pressure amplitude ratio)

(P → Pressure signal)

② $\omega_n = \sqrt{\frac{3\pi\mu^2 C^2}{4L\forall}}$ (Hz) (natural frequency)

(C → Velocity of Sound, L → Lenght, $\forall$ → Volume)

③ $C = 20.04\sqrt{T}$, $C = 49.1\sqrt{T}$

C: m/s when T is °K; ft/s when T is R

$R = F + 460$

4) $h = \frac{2\bar{u}}{\rho C r^3}\sqrt{\frac{3L\forall}{\pi}}$

- h: Damping Ratio
- ρ: density
- $\bar{u}$: Dynamic Viscosity 1.91×10^{-5} kg/m·s

5) $\bar{v} = \frac{M}{\rho}$

- $\bar{v}$: Kinematic Viscosity (m^2/s)
- M: Dynamic Viscosty
- ρ: Density

6) $\rho = \frac{P}{RT}$

- R: 287 J/kg·k°

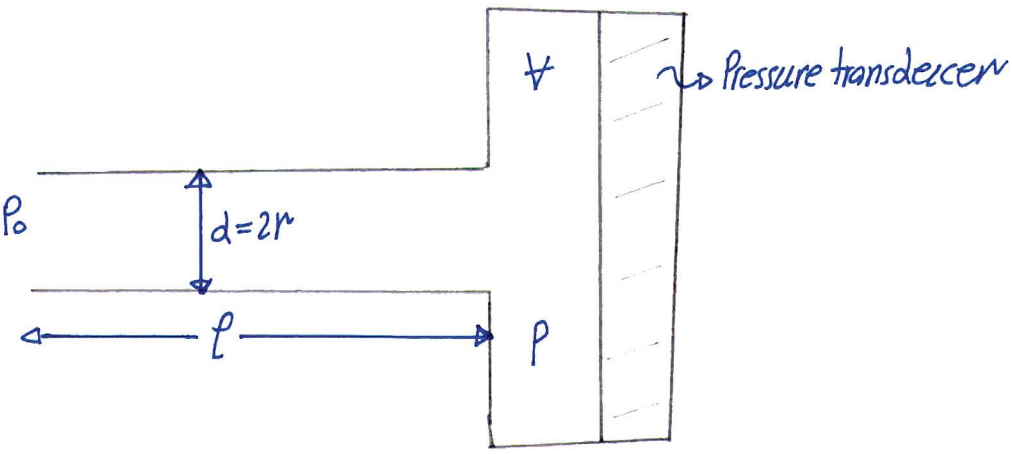
7) $\phi = \tan^{-1}\frac{-2h(\omega/\omega_n)}{1-(\omega/\omega_n)^2}$

↳ Phase angle.

⇒ If tube diameter is very small (Small tube)

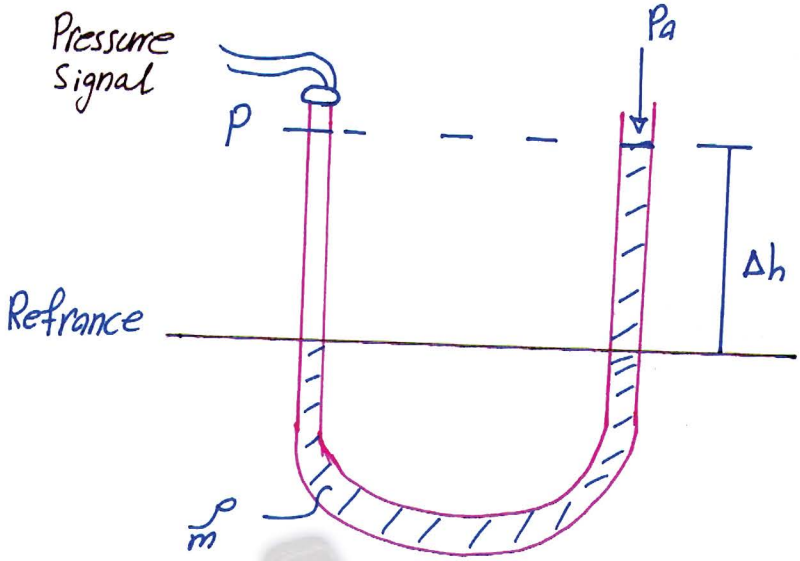
$$\left|\frac{P}{P_o}\right| = \frac{1}{\sqrt{1 + 4h^2(\omega/\omega_n)^2}}$$

$$\omega_n = \sqrt{\frac{\pi r^2 C^2}{\forall\left(l + \frac{1}{2}\sqrt{\pi^2 r^2}\right)}}$$



6.3 Mechanical Pressure – Measurment Devices.

1 U-tube manometer.



1. $\rho_m = S.G * \rho_w = 1000\ S.G$
2. $\rho_f = \rho_a = \frac{P_a}{RT}$
3. $P - P_a = \frac{g}{g_c} h (\rho_m - \rho_f)$
4. $\text{Sensitivity} = \frac{h}{P - P_a} = \frac{1}{(g/g_c)(\rho_m - \rho_f)}$

If $\rho_m = \rho_f$; $\text{Sensitivity} = \frac{1}{(g/g_c)\rho_m}$ $\quad g_c = 1\ \frac{kg.m}{N.s^2}$

5. $\gamma = \rho g$ 6. $P = \rho g h$

* $1\ in = 25.4\ mm$
* $1\ mm = 1\ torr = 133.3\ Pa$
* $P_{atm} = 14.7\ Psi$ ↳ $\frac{Lb}{in^2}$

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2$$

xample 6.2 | **NATURAL FREQUENCY FOR TUBE.** A small tube, 0.5 mm in diameter, is connected to a pressure transducer through a volume of 3.5 cm^3. The tube has a length of 7.5 cm. Air at 1 atm and 20°C is the pressure-transmitting fluid. Calculate the natural frequency for this system and the damping ratio.

Solution

We shall use Eq. (6.9) for this calculation. For air

$$\rho = \frac{p}{RT} = \frac{1.0132 \times 10^5}{(287)(293)} = 1.205 \text{ kg/m}^3$$

$$c = (20.04)(293)^{1/2} = 343 \text{ m/s}$$

$$\mu = 1.91 \times 10^{-5} \text{ kg/m} \cdot \text{ s (Table A.6, appendix)}$$

Thus,
$$\omega_n = \left\{ \frac{\pi(0.25 \times 10^{-3})^2(343)^2}{(3.5 \times 10^{-6})[0.075 + (0.5)(\pi)(0.25 \times 10^{-3})^{1/2}]} \right\}^{1/2}$$

$$= 296 \text{ Hz}$$

The damping ratio is calculated with Eq. (6.6):

$$h = \frac{(2)(1.91 \times 10^{-5})}{(1.205)(343)(0.25 \times 10^{-3})^3} \left[\frac{(3)(0.075)(3.5 \times 10^{-6})}{\pi} \right]^{1/2}$$

$$= 2.96$$

ATTENUATION IN TUBE. Calculate the attenuation of a 100-Hz pressure signal in the system of Example 6.2. | **Example 6.3**

Solution

For this calculation we employ Eq. (6.4). We have

$$\frac{\omega}{\omega_n} = \frac{100}{296} = 0.338$$

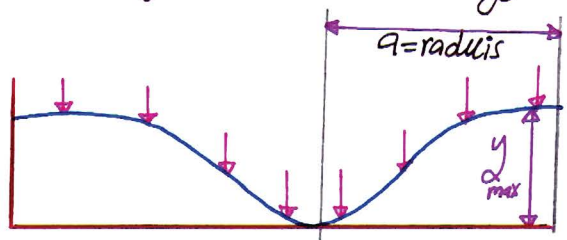
so that
$$\left| \frac{p}{p_0} \right| = \frac{1}{\{[1 - (0.338)^2]^2 + 4(2.96)^2(0.338)^2\}^{1/2}} = 0.457$$

6.4 DEAD - Weight Tester.

$$P = \frac{F}{A} = \frac{mg}{A}$$

6.5 Bordon tube Pressure Gage. (مقياس بوردون)

6.6 Diaphragm and Bellows Gage.



1. $$f = \frac{10.21}{a^2}\sqrt{\frac{g_c E t^2}{12(1-\bar{u}^2)\rho}}$$

f ← Natural frequency

2. $$y_{max} = \frac{3P}{16Et^3} a^4 (1-\bar{u}^2)$$

a ← raduse of diaphragm
$\bar{u}$ ← Posion Ratio
t ← thickness of diaphragm
y_{max} ← maximum deflection

$$y \leq \frac{t}{3} \rightarrow y_{max} = \frac{t}{3}$$

$$\boxed{\frac{t}{3} = \frac{3P}{16Et^3} a^4 (1-\bar{u}^2)}$$

$$E = \frac{\sigma}{\epsilon_o}$$

E ← moduls of elasticity

	SI	Britsh
P	Pa	$Psi = \frac{lb}{in^2}$
E	Pa	Psi
t	m	in
a	m	in
g_c	$1 \frac{kg \cdot m}{N \cdot s^2}$	$385.9 \frac{lbm \cdot in}{lbf}$
ρ	kg/m^3	lbm/in^3

For steel diaphragms

$$f = 1.934 * 10^6 \frac{t}{\pi a^2} \quad (t, a = in)$$

$$f = 4.912 * 10^4 \frac{t}{\pi a^2} \quad (t, a = m)$$

6.7 The Bridgman Gage.

$$R = R_1 (1 + b \Delta P)$$

- R: Resistance
- R_1: Resistance at 1atm
- b: Pressure Coefficient, $\frac{1.7*10^{-7}}{Psi}$, $\frac{2.5*10^{-11}}{Pa}$
- ΔP: gage Pressure

Bridge Circuit (Balance)

$R = R_x$

6.8 The Mcleod Gage

$$P = \frac{V_c y}{V_B - ay} = \frac{ay^2}{V_B - ay}$$

- P: Absolute Pressure (m)
- V_B: Volume m^3
- y: high of Liquid in the tube (m). → Gage reading.
- V_c: Volume of Capillary (m^3)
- a: area m^2
- $V_c = ay$, y: high (m)

if $ay << V_B$

$$P = \frac{V_c y}{V_B} = \frac{ay^2}{V_B}$$

$a = \frac{\pi}{4} d^2$ → Capillary diameter

$V_c = ay = \frac{\pi}{4} d^2 y$

$$P_c = P \frac{V_c}{V_B}$$

P_c: Pressure of Capillary

1 torr = 133.3 Pa

6.10 Pirani Thermal - Conductivity Gage

6.12 The Ionization Gage

6.13 The Alphatron.

Example 6.6 **NATURAL FREQUENCY OF A DIAPHRAGM GAGE.** A diaphragm pressure gag is to be constructed of spring steel ($E = 200$ GN/m^2, $\mu = 0.3$) 5.0 cm in diameter and i to be designed to measure a maximum pressure of 1.4 MPa. Calculate the thickness of th gage required so that the maximum deflection is one-third this thickness. Calculate the natur frequency of this diaphragm.

Solution

Using the relation from Fig. 6.10, we have

$$\frac{1}{3}t = \frac{3\,\Delta p}{16Et^3}a^4(1-\mu^2)$$

$$t^4 = \frac{(0)(1.4\times 10^6)(0.025)^4[1-(0.3)^2]}{(16)(2\times 10^{11})}$$

$$t = 1.09 \text{ mm}$$

We may calculate the natural frequency from Eq. (6.16)

$$f = \frac{10.21}{(0.025)^2}\left[\frac{(1.0)(2\times 10^{11})(0.00109)^2}{(12)[1-(0.3)^2](7800)}\right]^{1/2}$$

$$= 27{,}285 \text{ Hz}$$

Example 6.7

ERROR IN McLEOD GAGE. A McLeod gage has $V_B = 100\ \text{cm}^3$ and a capillary diameter of 1 mm. Calculate the pressure indicated by a reading of 3.00 cm. What error would result if Eq. (6.23) were used instead of Eq. (6.22)?

Solution

We have

$$V_c = \frac{\pi(1)^2}{4}(30.0) = 23.6\ \text{mm}^3$$

$$V_B = 10^5\ \text{mm}^3$$

From Eq. (6.22)

$$p = \frac{(23.6)(30.0)}{10^5 - 23.6} = 0.0071\ \text{torr} = 7.1\ \mu\text{m}\ (0.94\ \text{Pa})$$

The fractional error in using Eq. (6.23) would be

$$\text{Error} = \frac{ay}{V_B} = 2.36 \times 10^{-4}$$

or a negligibly small value.

6.10. A vacuum gage is to use an LVDT-diaphragm combination like that shown in Fig. 6.14. The LVDT has a sensitivity of 2.5 nm, and the diaphragm is to be constructed of steel (E = 2 × 1011 Pa, μ = 0.3) with a diameter of 15 cm. Calculate the diaphragm thickness in accordance with the restriction that the maximum deflection does not exceed one-third this thickness. What is the lowest pressure which may be sensed by this instrument?

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6.44. A McLeod gage has a capillary diameter of 0.2 mm and a volume VB of 125 cm3 What gage reading will result from an absolute pressure of 20 μm?

Sol

$d = 0.2\ mm$, $V_B = 125\ cm^3$, $P = 20\ \mu m$, Find y ?

$$P = \frac{\gamma V_c}{V_B} \rightarrow y^2 = \frac{PV_B}{a} = \frac{(20*10^{-6})(125*10^{-6})}{\frac{\pi}{4}(0.2*10^{-3})^2} = 0.282\ m$$

6.46. A microphone operates on the principle of a diaphragm gage with a capacitance pickup. Suppose a 140-dB sound-pressure source which produces a maximum pressure fluctuation of 0.029 psia in air is to be imposed on the diaphragm at a frequency of 5000 Hz. The diameter of the diaphragm is to be 1.0 cm. Determine the thickness for the diaphragm such that the natural frequency is 10,000 Hz. Assume spring-steel construction and a thickness of one-third the maximum displacement.

Sol

$140dB = 0.029 Psi = 200 Pa$

$a = 0.5\,cm$, $\omega_n = 10{,}000\,Hz$, $\omega = 5000\,Hz$

Spring steel → $E = 2*10^{11}$, $\rho = 7800$, $\mu = 0.3$

$$f = \frac{10.21}{a^2}\sqrt{\frac{g_c E t^2}{12(1-\mu^2)\rho}}$$

$$10{,}000 = \frac{10.21}{(0.5*10^{-2})^2}\sqrt{\frac{1*2*10^{11}*t^2}{12(1-0.3^2)*7800}}$$

$$t = 1.6*10^{-5}\,m$$

or

$$f = 4.912*10^4\frac{t}{\pi a^2}$$

* Find y_{max} ?

$$y_{max} = \frac{t}{3}$$

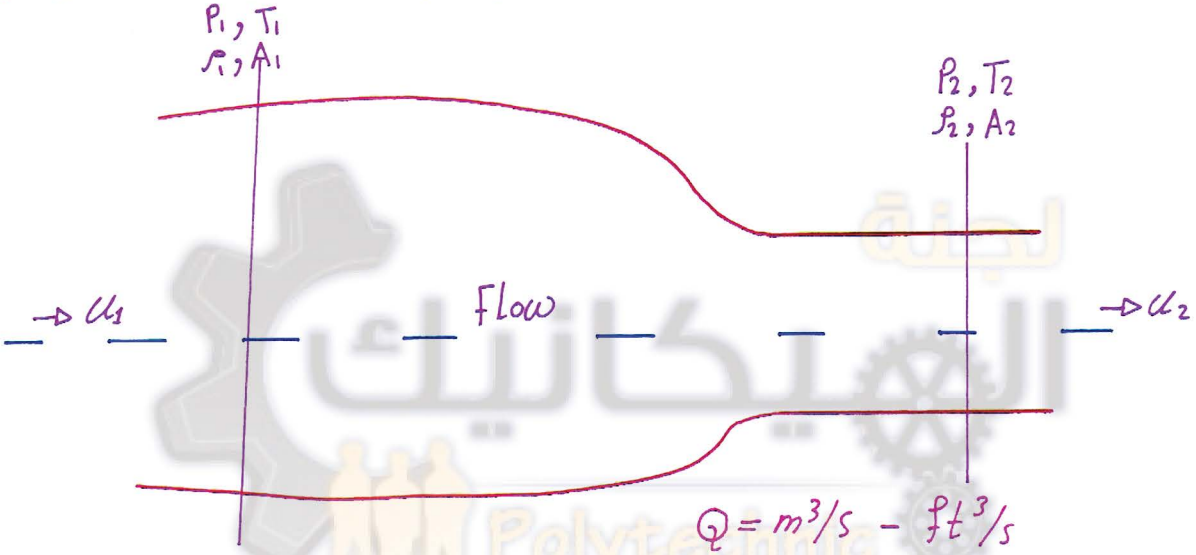
CH7

Flow Measurment

7.2 Positive displasment Method.

Pumps → Positive displasment.
→ negative displasment.

7.3 Flow - Obstruction Method.



$Q = m^3/s - ft^3/s$

$A = m^2 - in^2$

$\rho = kg/m^3 - lbm/ft^3$

$P = N/m^2 - lbf/ft^2$

$g_c = 1\ kg \cdot \frac{m}{N \cdot s^2} - 32.17\ \frac{lbm \cdot ft}{lbf \cdot s}$

$R = \frac{N \cdot m}{kg \cdot k} - \frac{lbf \cdot ft}{lbm \cdot R^\circ}$

$T = K - {}^\circ R$

[1] $\dot{m} = \rho_1 A_1 u_1 = \rho_2 A_2 u_2$

[2] $\frac{P_1}{\rho_1} + \frac{u_1^2}{2g_c} = \frac{P_2}{\rho_2} + \frac{u_2^2}{2g_c}$

[3] $P_1 - P_2 = \frac{u_2^2 \rho}{2g_c}\left[1 - \left(\frac{A_2}{A_1}\right)^2\right]$

[4] $Q = A_2 u_2 = \frac{A_2}{\sqrt{1-(A_2/A_1)^2}}\sqrt{\frac{2g_c}{\rho}(P_1 - P_2)}$

[5] $C = \frac{Q_{act}}{Q_{ideal}}$ [6] $P = \rho R T$

[7] $\dot{m} = A_2\sqrt{\frac{2g_c P_2}{RT_1}(P_1 - P_2)}$

= Discharge Coefficient (C).

$$C = \frac{Q_{act}}{Q_{th}}$$

↳ ideal

C

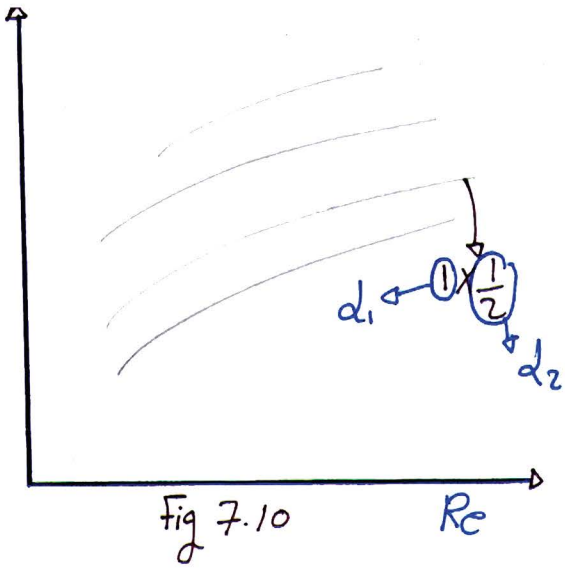
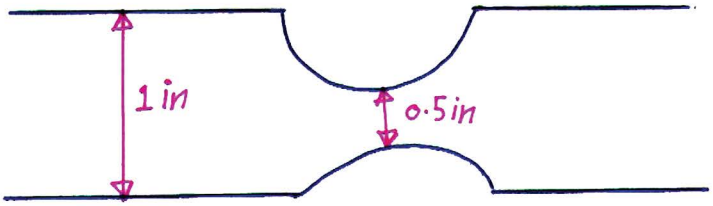
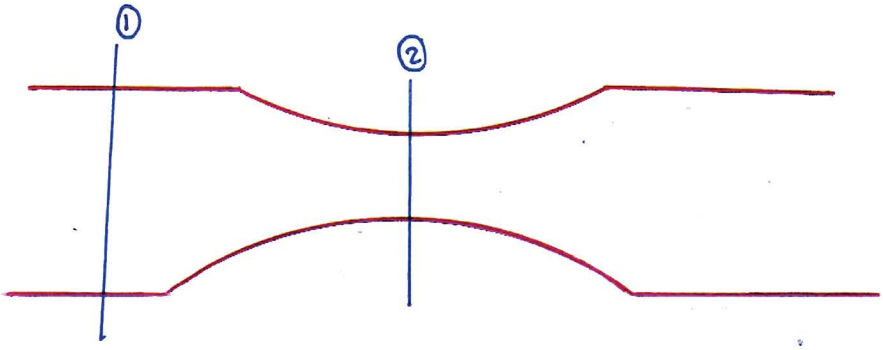


Fig 7.10

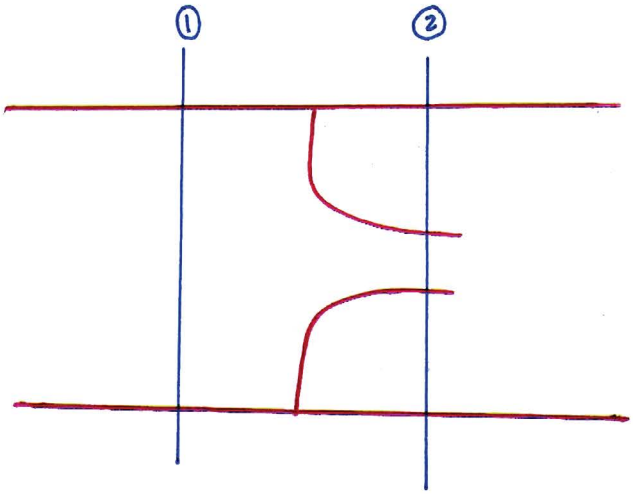


→ $\rho = \frac{m}{\forall}$ → mass (kg) → Volume (m^3) → $P = \rho R T$

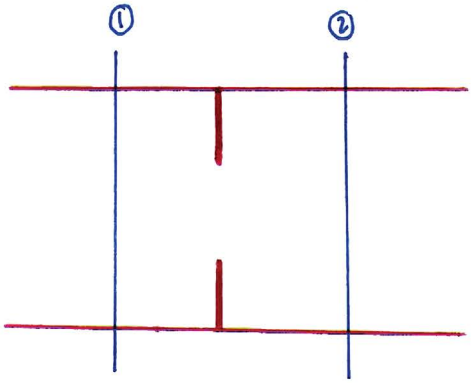
1 Venturi



2 Nozzle



[3] Orifice



Fluid → liquid InCompressible

→ Gas Compressible

$$\gamma = \frac{C_p}{C_v} = 1.4 \text{ Air}$$

→ InCompressible

[1] Venturis

$$Q_{act} = C M A_2 \sqrt{\frac{2g_c}{\rho}} \sqrt{P_1 - P_2}$$

[2] Nozzle and Orifices

$$Q_{act} = K A_2 \sqrt{\frac{2g_c}{\rho}} \sqrt{P_1 - P_2}$$

	SI	Britsh
Q	m^3/s	ft^3/s
A	m^2	ft^2
ρ	kg/m^3	Lbm/ft^3
g_c	$1 \frac{kg.m}{N.s^2}$	$32.17 \frac{Lbm.ft}{Lbf}$

→ Compressible

[1] Venturis (→ expansion factor)

$$\dot{m}_{act} = Y C m A_2 \sqrt{2 g_c \rho_1 (P_1 - P_2)}$$

[2] Nozzle and Orifices

$$\dot{m}_{act} = Y C M A_2 \sqrt{2 g_c \rho_1 (P_1 - P_2)}$$

[1] Velocity factor

$$M = \frac{1}{\sqrt{1 - (A_2/A_1)^2}} = \frac{1}{\sqrt{1 - (d_2/d_1)^4}}$$

* $Re = \frac{VD}{\nu} = \frac{\rho V D}{\mu}$

* Flow Coeff $K = CM$

* Diameter Ratio $\beta = \frac{d}{D} = \sqrt{\frac{A_2}{A_1}}$

xample 7.4 **DESIGN OF SONIC NOZZLE.** A sonic nozzle is to be used to measure a flow of air at 300 psia (2.07 MPa) and 100°F (37.8°C) in a 3-in-diameter pipe. The nominal flow rate is 1 lbm/s (0.454 kg/s). Calculate the throat diameter (nozzle size) such that just critical flow conditions are obtained.

Solution

We use Eq. (7.24) for this calculation with $\gamma = 1.4$ for air. The only unknown in this equation is A_2. Thus, we have

$$\dot{m} = CA_2 p_1 \sqrt{\frac{2g_c}{RT_1}} \left[\frac{\gamma}{\gamma+1} \left(\frac{2}{\gamma+1} \right)^{2/(\gamma-1)} \right]^{1/2}$$

$$1 = A_2(300)(144) \sqrt{\frac{(2)(32.2)}{(53.35)(560)}} \left[\left(\frac{1.4}{2.4} \right) \left(\frac{2}{2.4} \right)^{2/0.4} \right]^{1/2}$$

and $A_2 = 0.001078 \text{ ft}^2 = 0.1551 \text{ in}^2$ (1.0 cm^2).

The diameter at the throat is

$$d = \sqrt{\frac{4}{\pi}(0.1551)} = 0.444 \text{ in (1.13 cm)}$$

7.5 The Sonic Nozzle.

1. SubSonic (Mach No < 1).
2. Sonic = Same as Sound Velocity (Mach No = 1).
3. Super / altra } Sonic (Meach No > 1).

for the ideal gas with Constant specific heat, assuming isointropic flow Conditions.

$\Delta S = 0$
$\Delta Q = 0$

$$\left(\frac{P_2}{P_1}\right)_{Critical} = \left(\frac{2}{\gamma+1}\right)^{\gamma/\gamma-1}$$

$$\dot{m} = C A_2 P_1 \sqrt{\frac{2 g_c}{R T_1}\left[\frac{\gamma}{\gamma+1}\left(\frac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}}\right]}^{1/2}$$

↳ $C = 1$ (for air and gases)

$\gamma_{air} = 1.4$

	SI	Britsh
P	Pa	$lb/ft^2 = Psi^\circ$
$\dot{m}$	kg/s	lbm/s
R	J/kgk°	$\frac{ft.lbf}{Lbm\,R^\circ}$
T	K°	R°
A	m^2	in^2
g_c	1	32.17

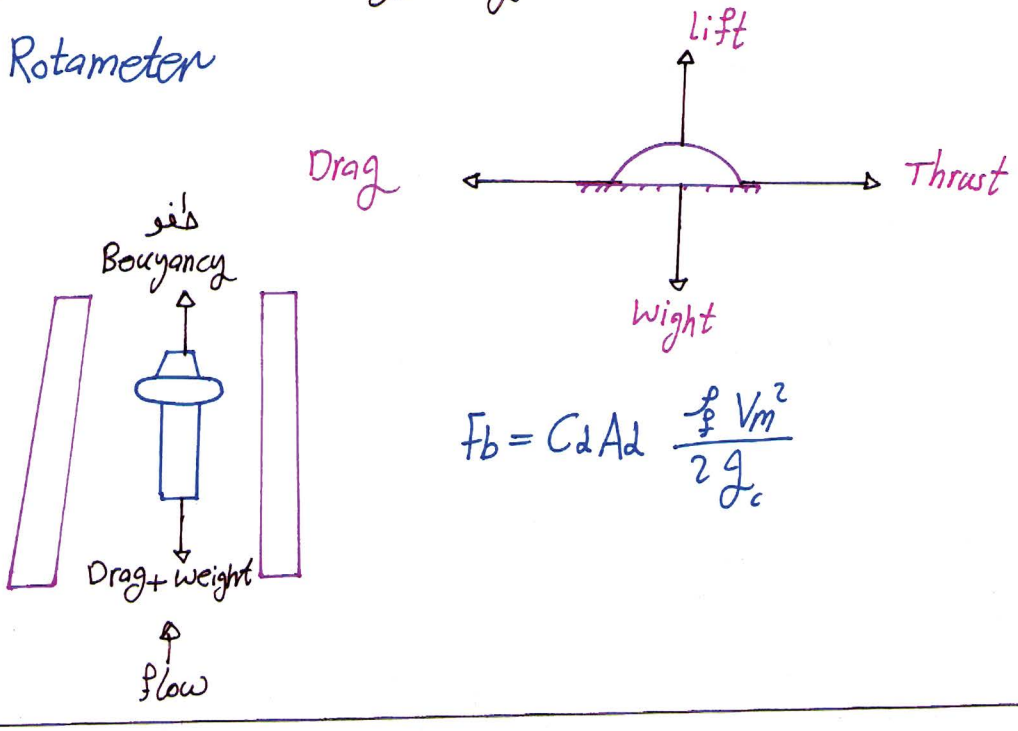
→ Turbine Meters

As the flow rate increases, the turbine wheel speed increases, so the magnetic field produces on electrical signal Propertinal to the flow rate speed.

$$Psi^\circ = \frac{lb}{in^2} * 144 = \frac{lb}{ft^2}$$

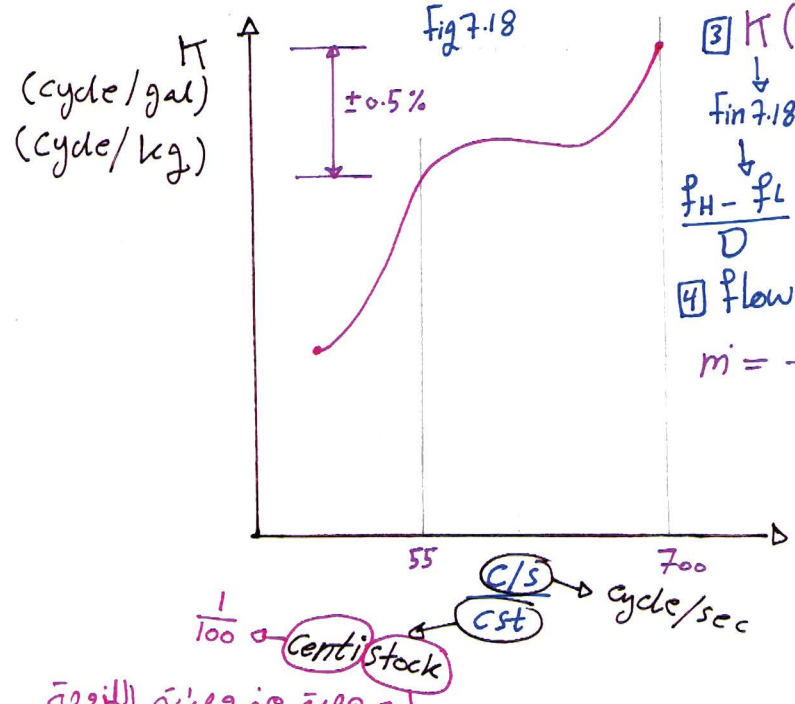
7.6 Flow Measurment By Drag Effect.

Rotameter



$$F_b = C_d A_d \frac{\rho_f V_m^2}{2 g_c}$$

Turbine Meter



[3] $K\left(\frac{cycle}{gal}\right) = \frac{cycle}{(231 in^3) * \rho(kg/m^3)}{(39.36\ in/m)^3}$

↓ Fin 7.18

$\frac{f_H - f_L}{D} = \frac{c/s}{cst} = K\left(\frac{cycle}{kg}\right)$

[4] flow rate.

$\dot{m} = \frac{f}{K} = \frac{(c/s)}{(c/kg)} = \frac{kg}{s}$

[1] $f = cst * (55-700)\frac{c/s}{cst} = c/s = Hz$

[2] $1\ cst = 10^{-6} m^2/s$

Example 7.6

FLOW COEFFICIENT FOR TURBINE METER. Calculate the range of mass flow rates of liquid ammonia at 20°C for which the turbine meter of Fig. 7.18 would be within ±0.5 percent. Also, determine a flow coefficient for this fluid in terms of cycles per kilogram.

Solution

From Fig. 7.18 the range for the ±0.5 percent calibration is approximately 55 to 700 cycles/s · cSt. From the appendix the properties of ammonia at 20°C are

$$\rho = 612 \text{ kg/m}^3$$
$$\nu = 0.036 \times 10^{-5} \text{ m}^2/\text{s}$$

The centistoke is defined from

1 stoke (cSt) = 10^{-4} square meter per second (m^2/s)
1 centistoke (cSt) = 10^{-6} square meter per second (m^2/s)

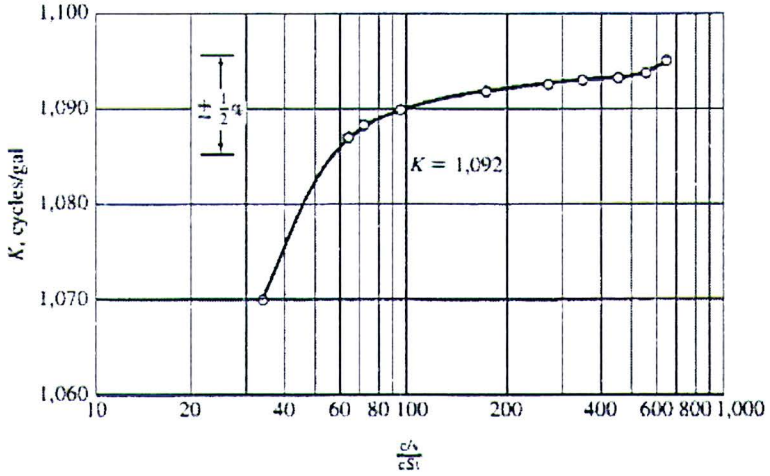


Figure 7.18 Calibration curve for 1-in-turbine flowmeter of the type shown in Fig. 7.17. Calibration was performed with water.

Therefore, $$\nu = \frac{0.036 \times 10^{-5}}{10^{-6}} = 0.26 \text{ cSt}$$

The frequency range is then

$$f_{\text{low}} = (55)(0.36) = 19.8 \text{ cycles/s}$$
$$f_{\text{high}} = (700)(0.36) = 252 \text{ cycles/s}$$

Also, 1 gal = 231 in^3 so that for ammonia

$$1 \text{ gal} = \frac{(231 \text{ in}^3)(612 \text{ kg/m}^3)}{(39.36 \text{ in/m})^3} = 2.318 \text{ kg}$$

The flow coefficient would then be

$$K = 1092 \text{ cycles/gal} = 471.1 \text{ cycles/kg}$$

and the range of flow rates for the 0.50 percent calibration would be

$$\dot{m}_{\text{low}} = \frac{19.8 \text{ cycles/s}}{471.1 \text{ cycles/kg}} = 0.042 \text{ kg/s}$$
$$\dot{m}_{\text{high}} = \frac{252}{471.1} = 0.535 \text{ kg/s}$$

7.15 Pressure Probes
مجسات الضغط.

[1] $\frac{P_{o_1}}{P_\infty} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}}$

- P_{o_1}: stagnation Pressure (befor shock wave).
- P_∞: free-stream Static Pressure
- M: Mach number

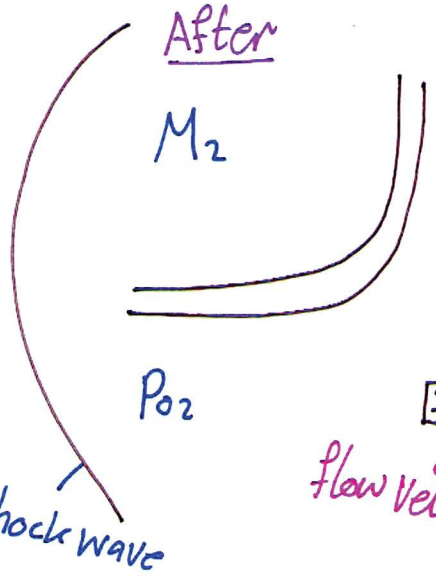
[4] $P_o - P_\infty = \frac{1}{2} \rho u_\infty^2$

Befor

$M_1 > 1$

P_{o_1}

P_∞



[2] $a = \sqrt{\gamma g_c R T}$ → °R

- a: accoustic Velocity / Mach
- R: J/lbm°R

[3] $u = a M$ — Mach No

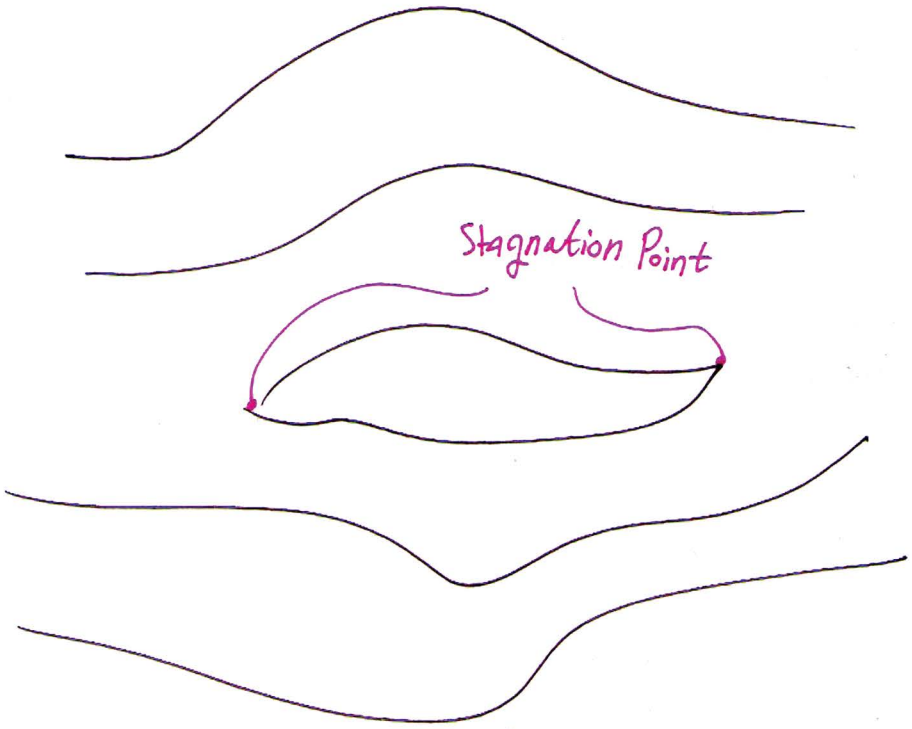
- u: flow Velocity
- a: accoustic Velocity / Mach

7.16 Impact Pressure in Super Sonic flow.

$$\frac{P_\infty}{P_{o_2}} = \frac{\left[(2\gamma/\gamma+1) M_1^2 - (\gamma-1)/\gamma+1)\right]^{\frac{1}{\gamma-1}}}{\left[(\gamma+1/2) M_1^2\right]^{\frac{\gamma}{\gamma-1}}}$$

- P_{o_2}: Impact Pressure behind the normal shock wave
- P_∞: Stagnation Pressure after shock wave

The Pitot tube



$$[1] \quad \rho = \frac{P_\infty}{RT_\infty}$$

$$[2] \quad u = \sqrt{\frac{2g_c(P_o - P_\infty)}{\rho}}$$

$P_o - P_\infty$ = dynamic Pressure

u = Velocity

Example 7.10

VELOCITY MEASUREMENT WITH PITOT TUBE. A Pitot tube is inserted in a flow stream of air at 30°C and 1.0 atm. The dynamic pressure is measured as 1.12 in water when the tube is oriented parallel to the flow. Calculate the flow velocity at that point.

Solution

We use Eq. (7.55) for this calculation. The air density is calculated as

$$\rho = \frac{p_\infty}{RT_\infty} = \frac{1.0132 \times 10^5}{(287)(303)} = 1.165\,\text{kg/m}^3$$

We also have

$$p_0 - p_\infty = 1.12\,\text{in water} = 5.82\,\text{psf} = 278.7\,\text{Pa}$$

so that the velocity is

$$u_\infty = \sqrt{\frac{2(p_0 - p_\infty)}{\rho}} = \left[\frac{(2)(278.7)}{1.165}\right]^{1/2}$$

$$= 21.9\,\text{m/s}\,(71.8\,\text{ft/s})$$

Example 7.11

DETERMINATION OF VOLUME FLOW RATE USING PITOT TUBE. A Pitot tube is used to measure the dynamic pressure $p_0 - p_\infty$ for air in a 4-in-diameter duct. The air conditions are 14.7 psia and 70°F (530°R). The readings are shown in the accompanying table for five radial positions measured from the center of the duct. No measurement is taken at the outside radius where the velocity is assumed zero. For the first reading at the center of the duct the velocity is calculated from

$$p_0 - p_\infty = \frac{\rho u^2}{2g_c} \qquad \textbf{[a]}$$

with the density of air calculated from

$$\rho = \frac{p}{RT} = (14.7)(144)/(53.35)(530) = 0.0748\,\text{lbm/ft}^3 \qquad \textbf{[b]}$$

Then, with $p_0 - p_\infty = 2.87\,\text{in}H_2O = 14.92\,\text{lbf/ft}^2$,

$$u = \left[\frac{(2)(32.17)(14.92)}{0.748}\right]^{1/2} = 113\,\text{ft/s} \qquad \textbf{[c]}$$

Example 7.12 **IMPACT TUBE IN SUPERSONIC FLOW.** A probe like that shown in Fig. 7.45 is placed in an airflow stream where $M_1 = 2.5$ and the free-stream static pressure is measured as 22 kPa. Determine the stagnation pressure before and after the shock wave.

Solution

We employ Eq. (7.56) for this calculation of p_{0_2} with $M_1 = 2.5$ and $\gamma = 1.4$ for air. Thus,

$$\frac{p_\infty}{p_{0_2}} = \frac{\{[(2)(1.4)/(2.4)](2.5)^2 - (0.4)/(2.4)\}^{1/0.4}}{\{[(2.4)(2)](2.5)^2\}^{1.4/0.4}}$$

$$= 0.1173$$

and

$$p_{0_2} = \frac{22}{0.1173} = 187.6\,\text{kPa}$$

The stagnation pressure upstream of the shock wave is calculated from Eq. (7.49):

$$\frac{p_{0_1}}{p_\infty} = \left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{\gamma/(\gamma-1)}$$

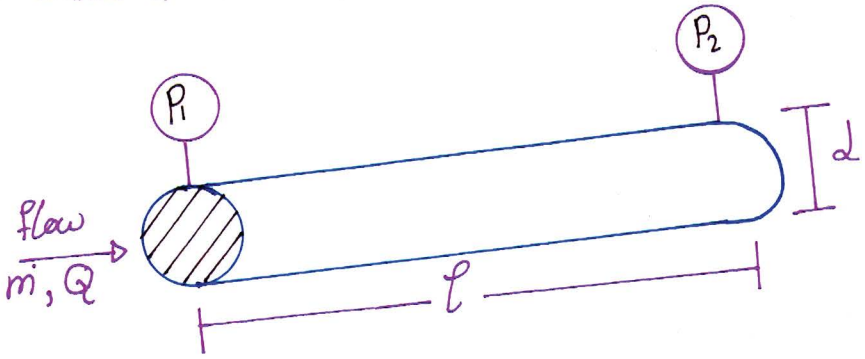
$$= [1 + (0.2)(2.5)^2]^{1.4/0.4}$$

$$= 17.086$$

and

$$p_{0_1} = (22)(17.086) = 375.9\,\text{kPa}$$

Laminar Flowmeter.



1. $Re = \frac{\rho V d}{\mu}$.
2. $Q = VA$.
3. $\dot{m} = \frac{Re \pi d \mu}{4}$.
4. $\forall = \frac{RT}{P}$ (standerd Volume). (1atm , 20°c)
5. $\dot{V} = \forall \dot{m}$

$$1 \frac{kg}{s} = 2.205 \frac{lbm}{s}$$

	SI	Britsh
Q	m^3/s	ft^3/s , in^3/s
$\dot{m}$	kg/s	lbm/s
$\forall$	m^3/kg	ft^3/lbm
T	$K°$	$F°, R$
P	Pa , N/m^2	Lbf/in^2
R	$287\ J/kg°K$	$53.35\ \frac{ft.lbf}{lbm.R°}$
$\dot{V}$	SCCM	SCFM

Pressure → $14.7 \frac{Lbf}{in^2}$

→ 101 kPa

Density → $\rho_{air} = 1.114$ at 40°c, 1atm

ex:- 400kPa = 4atm

$\rho = 1.114\,(4) = 4.456$ atm

Q4 Air at 400 kPa and 40 C flow in a circular tube having a diameter of 5 cm at a rate such that the Reynolds number is 50,000 calculate the flow rate in unit of kg/s, lbm/min,SCFM. cm^3/s and SCCM.

Note

① SCFM = Standard Cubic feet per minute.

② SCCM = Standard Cubic Centimeters per minute.

SI

$$\dot{m} = \frac{Re\,\pi\,d\,\mu}{4} = \frac{50000*\pi*5*10^{-2}*1.86*10^{-5}}{4}$$

$$= 0.0365\ kg/sec \quad \#Ans$$

$$V = \frac{Re\,\mu}{\rho d} = \frac{50000*1.86*10^{-5}}{(4)(1.114)(0.05)}$$

$$= 4.174\ m/s$$

$$Q = V*A$$

$$= 4.174*\frac{\pi}{4}(5*10^{-2})^2$$

$$= 8.2*10^{-3}\ m^3/sec$$

$$= 8.2*10^{-3}*10^6 = 8200\ cm^3/sec \quad *Ans$$

$$\forall = \frac{RT}{P} = \frac{287\,(313)}{400*10^3}$$ ← لفوق

$$= \frac{287\,(293)}{1.01*10^5} = 0.83\ m^3/kg$$

$$\dot{V} = \dot{m}\forall = 0.83*0.0365 = 0.030295\ m^3/sec$$

$$0.030295*10^6*60 = 1817700\ \frac{cm^3}{min}$$

Britsh

$$1\ kg/sec = 2.205\ lbm/s$$

$$0.0365\ kg/sec = X$$

$$\dot{m} = X = 0.0804\ lbm/s$$

$$\dot{m} = 4.829\ lbm/min \quad *Ans$$

$$\forall = \frac{53.35*528}{(14.65)(144)}$$ ← للتحويل إلى lbf/ft^2

lbf/in^2

$$= 13.35\ ft^3/lbm$$

$$\dot{V} = \forall\dot{m} = 13.35*4.829 = 64.48\ ft^3/min$$

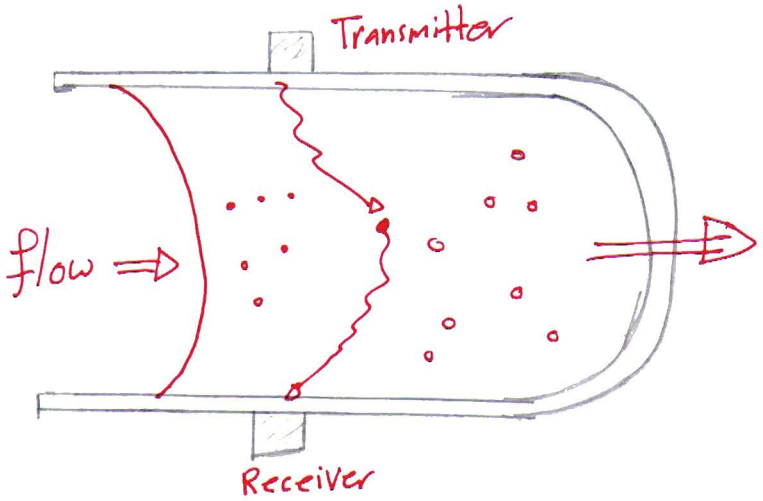
SCFM *Ans

* 7.8// Magnetic flowmeters

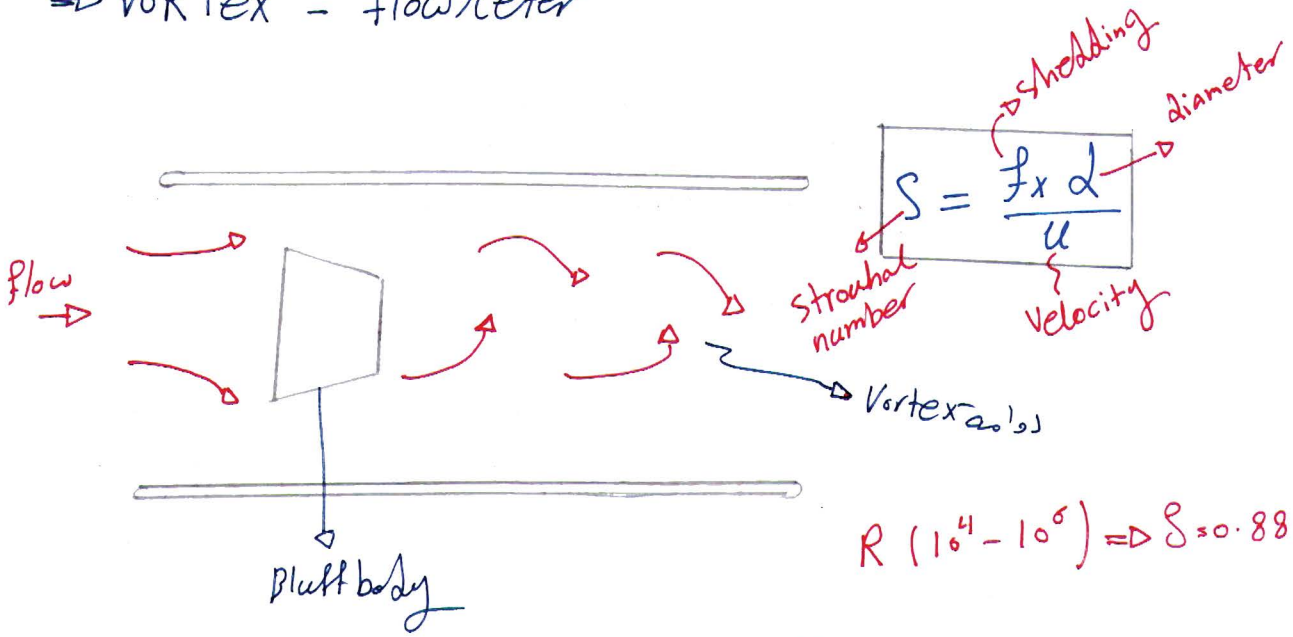
$$F = BLu \times 10^{-8} \; V$$

- L: Length of the conductor (cm)
- B: Magnetic flux density (gauss)
- u: Velocity of the conductor (cm/s)

=> Ultrasonic flow Meter



=> VoRTex - flowMeter



$R\ (10^4 - 10^5) \Rightarrow S = 0.88$

7.25. A small sonic nozzle having a throat diameter of 0.8 mm is used to measure and regulate the flow in a 7.5-cm-diameter line. The upstream pressure on the nozzle is varied in accordance with the demand requirements. The downstream pressure is always low enough to ensure sonic flow at the throat. What is the flow rate for upstream conditions at 20◦C and 1.0 MPa?

Sol

$$\dot{m} = C A_2 P_1 \sqrt{\frac{2g_c}{RT_1}} \left[\frac{\gamma}{\gamma+1}\left(\frac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}}\right]^{1/2}$$

$$= (1)\left(\frac{\pi}{4}(7.5*10^{-2})^2\right)(1*10^{6}) \sqrt{\frac{2*1}{(287)(293)}} \left[\frac{1.4}{1.4+1}\left(\frac{2}{1.4+1}\right)^{\frac{2}{1.4-1}}\right]^{1/2}$$

$$= 1.187*10^{-3}\ kg/sec.$$

7.26. An impact tube is used to measure the Mach number of a certain airflow in a wind tunnel. The static pressure is 3 psia, and the impact pressure at the probe is 116 kPa. What is the Mach number of the flow ($\gamma = 1.4$ for air)? If the free-stream air temperature is $-40^\circ C$, what is the flow velocity?

Sol

$$\frac{P_\infty}{P_{o_2}} = \frac{\left(\left(\frac{2\gamma}{\gamma+1}\right)M^2 - \frac{(\gamma-1)}{\gamma+1}\right)^{1/\gamma-1}}{\left(\left(\frac{\gamma+1}{2}\right)M^2\right)^{\gamma/\gamma-1}}$$

$$\frac{3*6.89}{116} = \frac{(1.167M^2 - 0.167)^{2.5}}{(1.2M^2)^{3.5}}$$

$$M = 2.03$$

$$u = aM \quad , \quad a = \sqrt{\gamma g_c R T} = \sqrt{1.4*287*233}$$

$$= 305.97 * 2.03 \qquad = 305.97$$

$$= 620.97 \text{ m/sec}$$

7.42. An impact tube is used with an airflow at 10◦C, 40 kPa, and a velocity of 700 m/s. What pressure will be indicated by the probe?

Sol

$$a = \sqrt{\gamma g_c RT} = \left((1.4)(287)(283)\right)^{1/2} = 337 \text{ m/s}$$

$$M = \frac{u}{a} = \frac{700}{337} = 2.076$$

$$\frac{P_\infty}{P_{o2}} = \frac{\left(\left(\frac{2\gamma}{\gamma+1}\right)M^2 - \left(\frac{\gamma-1}{\gamma+1}\right)\right)^{\frac{1}{\gamma-1}}}{\left(\left(\frac{\gamma+1}{2}\right)M^2\right)^{\frac{\gamma}{\gamma-1}}}$$

$$P_{o2} = 241 \text{ kPa}$$

CH8

The Measurment of Temperature

⇒ Thermistors

$$R = R_o e^{[B(\frac{1}{T} - \frac{1}{T_o})]}$$

R_o = resistance at the referance temp.

T_o = referance temp.

B = Constant.

T = final (needed) temp.

R = resistance at temp T

Uncertainty

$$W_T = \sqrt{\left[\left(\frac{B/R_o}{(\ln\frac{R}{R_o} + \frac{B}{T_o})^2}\right)(W_{R_o})\right]^2 + \left[\left(\frac{-B/R}{(\ln\frac{R}{R_o} + \frac{B}{T_o})^2}\right)(W_R)\right]^2}$$

8.6 Temp Measurment By Radiation.

$E = \sigma T^4$ σ = stefan-Boltzmann Constant

$= 0.1714 \times 10^{-8}$ Btu/h.ft^2.R^4

$= 5.669 \times 10^{-8}$ W/m^{2}K^4

E = Btu/h.ft^2 - W/m^2

T = absolute temp $\dot{R}$ - K

$E = \epsilon\sigma T^4 \rightarrow T = \left(\frac{E}{\epsilon\sigma}\right)^{1/4}$

For blackbody $\epsilon = 1$

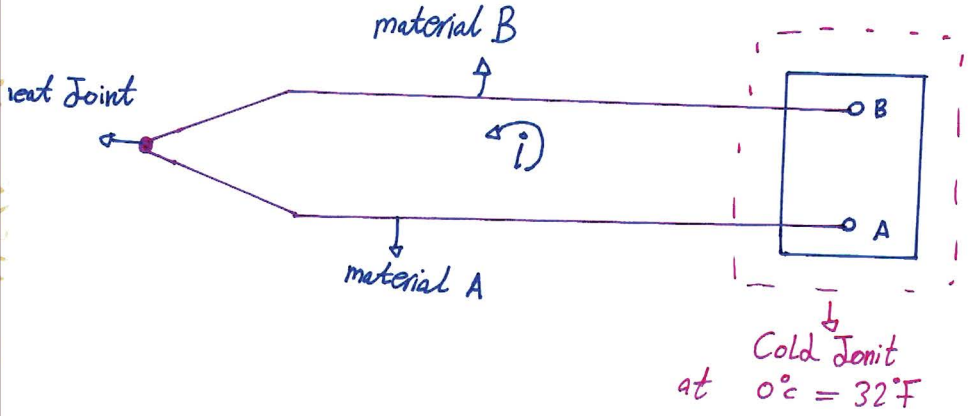
$$T_a = \left(\frac{E}{\sigma}\right)^{1/4}$$

$$Error = \frac{T - T_a}{T} = 1 - \frac{T_a}{T} = 1 - \epsilon^{1/4}$$

$$F = \frac{q}{A}$$

$$F = \epsilon_1 \sigma T_1^4 = \epsilon_2 \sigma_2 T_2^4$$

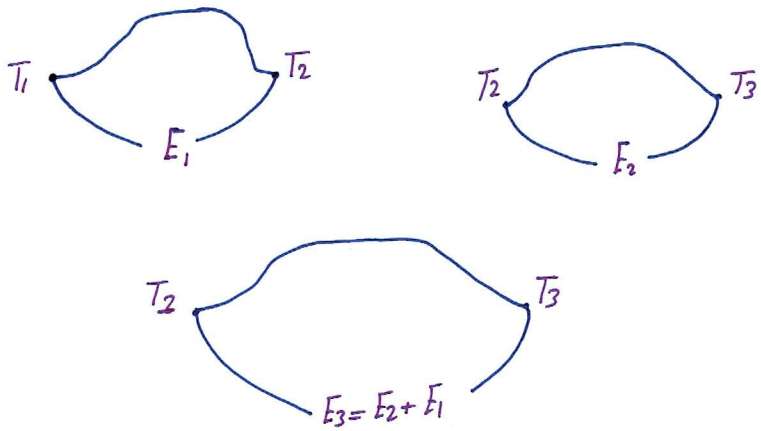
=> Thermo Couple



The three thermo Couple effect.

① Seebeck effect. ② Themson effect.

③ Peltier effect.



TYPes of thermo Couples Table 8.3 (9)

Copper and Constan Chromel vs Constan

$$\Rightarrow \text{Sensitivty} = \frac{\text{diff Voltage}}{\text{diff temp}} = \frac{mv}{°F} \text{ or } \frac{mv}{°C}$$

able 8.3a Thermal emf in absolute millivolts for commonly used thermocouple combinations, according to ITS(90) (Reference junction of 0°C)[1]

:mperature, °C	Copper vs. Constantan (*T*)	Chromel vs. Constantan (*E*)	Iron vs. Constantan (*J*)	Chromel vs. Alumel (*K*)	Platinum vs. Platinum–10% Rhodium (*S*)	Nicosil vs. Nisil (*N*)
−150	−4.648	−7.279	−6.500	−4.913		−1.530
−100	−3.379	−5.237	−4.633	−3.554		−1.222
−50	−1.819	−2.787	−2.431	−1.889	−0.236	−0.698
−25	−0.940	−1.432	−1.239	−0.968	−0.127	−0.368
0	0	0	0	0	0	0
25	0.992	1.495	1.277	1.000	0.143	0.402
50	2.036	3.048	2.585	2.023	0.299	0.836
75	3.132	4.657	3.918	3.059	0.467	1.297
100	4.279	6.319	5.269	4.096	0.646	1.785
150	6.704	9.789	8.010	6.138	1.029	2.826
200	9.288	13.421	10.779	8.139	1.441	3.943
300	14.862	21.036	16.327	12.209	2.323	6.348
400	20.872	28.946	21.848	16.397	3.259	8.919
500		37.005	27.393	20.644	4.233	11.603
600		45.093	33.102	24.906	5.239	14.370
800		61.017	45.494	33.275	7.345	20.094
1000		76.373	57.953	41.276	9.587	26.046
1200			69.553	48.838	11.951	32.144
1500					15.582	
1750					18.503	

[1] Composition of Thermocouple Alloys:
Alumel: 94% nickel, 3% manganese, 2% aluminum, 1% silicon
Chromel: 90% nickel, 10% chromium
Constantan: 55% copper, 45% nickel
Nicosil: 84% nickel, 14% chromium, 1.5% silicon
Nisil: 95% nickel, 4.5% silicon, 0.1% Mg

8.8. It is desired to measure a temperature differential of 5◦F using copper-constantan thermocouples at a temperature level of 200◦F. A millivolt recorder is available for the emf measurement which has an uncertainty of 0.004 mV. Precision thermocouple wire is available, which may be assumed to match the characteristics in Table 8.3 exactly. How many junction pairs in a thermopile must be used in order that the uncertainty in the temperature differential measurement does not exceed 0.05◦F? Neglect all errors due to heat transfer.

Temp diff = 5°F , temp level = 200°F * Uncertainty = 0.004mV

* Uncertainty temp = 0.05°F * Copper-Constantan (T)

find number of Junction ?

Sol ΔT x difference For 1F x number of Junction = R

Table 8.3(a)

Temp (°F)	T (mv)
150	2.72
200	3.973
250	5.3

-50°F ↑ temp Level ↓ +50°F

diff temp = 250 − 150 = 100°F

diff volt = 5.3 − 2.72 = 2.58mv

150°F = 65.6°C

Tabel 8.3(a) Interpolation

50 → 2.036
65.6 → X
75 → 3.132

X = 2.72 mv

200°F = 93.33°C

Table 8.3(a)

75 → 3.132
93.33 → X
100 → 4.279

X = 3.973 mv

250°F = 121.1°C

Table 8.3 (a).

100 → 4.279
121.1 → X
150 → 6.704

X = 5.3 mv

[1] Sensitivity $= \frac{\Delta \text{ Voltage}}{\Delta \text{ temp}} = \frac{2.58}{100} = 0.0258 \frac{mV}{°F}$

[2] $\frac{\omega_V}{V} = \frac{\omega_{\Delta T}}{\Delta T}$

$\frac{0.004}{V} = \frac{0.05}{5} \rightarrow V = 0.4 mV = R$

$\rightarrow 5 \times 0.0258 \times n = 0.4$

$n = 3.1$

EFFECT OF EMISSIVITY ON TEMPERATURE MEASUREMENT. The energy emitted from a piece of metal is measured, and the temperature is determined to be 1050°C, assuming a surface emissivity of 0.82. It is later found that the true emissivity is 0.75. Calculate the error in the temperature determination.

Solution

$$E_1 = E_2$$

$$\epsilon_1 \sigma T_1^4 = \epsilon_2 \sigma T_2^4$$

$$0.82 (1050 + 273)^4 = 0.75\, T_2^4$$

$$T_2 = 1352.8\,K$$

$$Error = \frac{\Delta T}{T_1} = \frac{29}{1323} \cong 0.022$$

(10 mark)

8.10. For a certain thermistor β = 3420 K, and the resistance at 200◦F is known to be 1010 ± 3 . The thermistor is used for a temperature measurement, and the resistance is measured as 2315 ± 4 . Calculate the temperature and the uncertainty.

Sol

[1] $$\ln\frac{R}{R_o} = \left(\frac{B}{T} - \frac{B}{T_o}\right)$$

$$\frac{B}{T} = \ln\frac{R}{R_o} + \frac{B}{T_o}$$

$$T = \frac{B}{\left(\ln\frac{R}{R_o}\right) + \left(\frac{B}{T_o}\right)}$$

$$\frac{\partial T}{\partial R_o} = \frac{-B\,(-1/R_o)}{\left[\left(\ln\frac{R}{R_o} + \frac{B}{T_o}\right)^2\right]}$$

$$\frac{\partial T}{\partial R} = \frac{-B\,(1/R)}{\left[\ln\frac{R}{R_o} + \frac{B}{T_o}\right]^2}$$

$$\omega_T = \sqrt{\left[\left(\frac{B/R_o}{\left(\ln\frac{R}{R_o} + \frac{B}{T_o}\right)^2}\right)\omega_{R_o}\right]^2 + \left[\left(\frac{-B/R}{\left(\ln\frac{R}{R_o} + \frac{B}{T_o}\right)^2}\right)(\omega_R)\right]^2} = 0.1135\,k$$

$\omega_{R_o} = 3$

$\omega_R = 4$

$T_o = (200-32)\frac{5}{9} + 273.16 = 366.5\,k$

[2] $$R = R_o\, e^{\left[B\left(\frac{1}{T} - \frac{1}{T_o}\right)\right]}$$

$$2315 = 1010\, e^{\left[3420\left(\frac{1}{T} - \frac{1}{366.5}\right)\right]}$$

$$T = 336.6\,k$$

أسئلة سنوات

2019

Q1 Asteel tape is used to measure a distance of 20 m at 10-C. Assuming that the tape will messure the true distance when the temperature is 20-C.what would be the indicated distance at 10C? what would be the indicated distance at 40-C?

Sol $\alpha = 11.65 * 10^{-6}/^{\circ}C$, True reading $= 20^{\circ}C$

At $10^{\circ}c$

$L = L_o (1 + \alpha (T - T_o))$

$20 = L_o (1 + 11.65 * 10^{-6} (10 - 20)) \rightarrow L_o = 20.00233\ m$

At 40°

$20 = L_o (1 + 11.65 * 10^{-6} (40 - 20)) \rightarrow L_o = 19.99534 m$

Q2 McLeod gage has a capillary diameter of 0.2 mm and a volume. VB of 125 cm3.What gage rending will result from an absolute pressure of 20 um?

Sol

$$P = \frac{ay^2}{V_B - ay}$$

$y \rightarrow$ gage reading

$$(20 * 10^{-6}) = \frac{\pi/4\,(0.2*10^{-3})^2\, y^2}{125*10^{-6} - \pi/4\,(0.2*10^{-3})^2\, y}$$

$$\therefore y = 0.282\ m$$

able 8.3a Thermal emf in absolute millivolts for commonly used thermocouple combinations, according to ITS(90) (Reference junction of 0°C)[1]

:mperature, °C	Copper vs. Constantan (*T*)	Chromel vs. Constantan (*E*)	Iron vs. Constantan (*J*)	Chromel vs. Alumel (*K*)	Platinum vs. Platinum–10% Rhodium (*S*)	Nicosil vs. Nisil (*N*)
−150	−4.648	−7.279	−6.500	−4.913		−1.530
−100	−3.379	−5.237	−4.633	−3.554		−1.222
−50	−1.819	−2.787	−2.431	−1.889	−0.236	−0.698
−25	−0.940	−1.432	−1.239	−0.968	−0.127	−0.368
0	0	0	0	0	0	0
25	0.992	1.495	1.277	1.000	0.143	0.402
50	2.036	3.048	2.585	2.023	0.299	0.836
75	3.132	4.657	3.918	3.059	0.467	1.297
100	4.279	6.319	5.269	4.096	0.646	1.785
150	6.704	9.789	8.010	6.138	1.029	2.826
200	9.288	13.421	10.779	8.139	1.441	3.943
300	14.862	21.036	16.327	12.209	2.323	6.348
400	20.872	28.946	21.848	16.397	3.259	8.919
500		37.005	27.393	20.644	4.233	11.603
600		45.093	33.102	24.906	5.239	14.370
800		61.017	45.494	33.275	7.345	20.094
1000		76.373	57.953	41.276	9.587	26.046
1200			69.553	48.838	11.951	32.144
1500					15.582	
1750					18.503	

[1] Composition of Thermocouple Alloys:
Alumel: 94% nickel, 3% manganese, 2% aluminum, 1% silicon
Chromel: 90% nickel, 10% chromium
Constantan: 55% copper, 45% nickel
Nicosil: 84% nickel, 14% chromium, 1.5% silicon
Nisil: 95% nickel, 4.5% silicon, 0.1% Mg

Q4 A radiant energy measurment is made to determine the temp of a hot block of metal. The emitted energy from the surface of the metal is measured as $28 \pm 0.4 kW/m^2$ and the surface emissivity is estimate the $\epsilon = 0.9 \pm 0.05$. Calculate the surface temp and estimate the uncertainty.

Sol $\quad E = \sigma \epsilon T^4$

$$T = \left(\frac{E}{\epsilon \sigma}\right)^{1/4} = \left(\frac{28000}{0.9 * 5.668 * 10^{-8}}\right)^{1/4} = 860.74^{\circ}K$$

$$\frac{W_T}{T} = \frac{1}{4}\left[\left(\frac{W_E}{E}\right)^2 + \left(\frac{W_\epsilon}{\varepsilon}\right)^2\right]^{1/2}$$

$$= \frac{1}{4}\left[\left(\frac{0.4}{28}\right)^2 + \left(\frac{0.05}{0.9}\right)^2\right]^{1/2} = 0.01434$$

$$W_T = T * 0.01434 = 860.74 * 0.01434 = 12.34^{\circ}c$$

Q_5 It is desired to measure a temp differential of 10°F using Copper-Constantan thermocouple at a temp level of 300°F. A millivolt recorder is available for the emf measurment which has an uncertainty of 0.008 mv. Precision thermocouple wire is available, which may be assumed to match the characteristics of the thermocouples table. How many junction pairs in a thermopile must be used in order that the uncertainty in the temp differential measurment does nat exceed 0.07°F ?

Sol

Temp (°F)	T (mv)
250	5.3
300 (temp Level)	—
350	8.08

diff temp = 350 − 250 = 100°F

diff Volt = 8.08 − 5.3 = 2.78 mv

250°F = 121.1°C

100 → 4.279

121.1 → X

150 → 6.704

X = 5.3 mv

350°F = 176.66°C

150 → 6.704

176.66 → X

200 → 9.288

X = 8.08 mv

$$\text{Sensitivity} = \frac{\Delta \text{Volt}}{\Delta \text{temp}} = \frac{2.78}{100} = 0.0278 \frac{mV}{°F}$$

$$\frac{\omega_T}{\Delta T} = \frac{\omega_V}{V}$$

$$\frac{0.07}{10} = \frac{0.008}{V} \rightarrow V = 1.143 mv$$

$$\Delta T \times \text{Sensitivity} \times n = R$$

$$10 \times 0.0278 \times n = 1.143$$

GOOD LUCK

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2019/SUMMER